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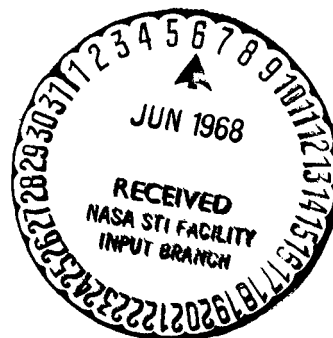
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FOREWORD

Publication of the results of studies on the upper atmosphere by spectral and electrophotometrical methods is continued in this collection. The contents of the articles were presented at the First All-Union Conference on the results of the IGY in Moscow from January 24 to February 5, 1963, and at a special extended sèminar by the Department of Physics of the Upper Atmosphere in the Institute of Physics of the Atmosphere of the Academy of Sciences U.S.S.R. from May 21 to 24, 1963, in the State Astronomics Institute imeni P. K. Shternberg.

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VARIATIONS OF THE SPECTRAL DISTRIBUTION OF THE AIRGLOW CONTINUUM

Yu. L. Truttse

ABSTRACT: Spatial and time variations of the integral continuum spectral distribution for the regions $\lambda 5700 \text{ \AA}$ and $\lambda 5300 \text{ \AA}$ have been obtained from scanning photometer observations. The limits of the variations are from -24% to +9% of the mean value. The integral continuum atmospheric and extra-atmospheric components have different spectral distribution.

INTRODUCTION

A study of the airglow continuum spectral distribution and its variations is of substantial significance in determining the mechanism of the continuum excitation. Moreover, a fairly good knowledge of its spectral distribution is absolutely necessary in order to estimate correctly the background during photoelectric observations of discrete emissions of the night sky, separated by interference filters with the width of an equivalent band of complete filtration $\Delta\lambda \approx 50 \text{ \AA}$. /6*

In the last 30 years, a rather large number of studies have been conducted on the continuum spectral distribution. In order to use the literature, we must introduce a value, which can characterize the spectral distributions obtained by various authors, in a single system. The continuum has several components. These components, obviously, can be the real continuous radiation as well as weak diffuse forbidden molecular bands [1,2]. Spectral distribution of these components is varied, and the relationship among them is different for various spectral ranges and can rapidly change with a change in the wavelength [3-5]. Therefore, an introduction to an understanding of the correspondence between the type of continuum and the spectral class of stars is inconvenient, since, even in a short spectral range, we can obtain a similarity among the various spectral classes [4]. It would be more convenient to introduce a numerical coefficient j for the range being studied, similar to the

* Numbers in the margin indicate pagination in the foreign text.

color index C which characterizes the relationship between the continuum intensities per 1 Å in ranges with wavelengths λ_1 and λ_2 . For the spectral range which interests us we chose the sections $\lambda_1 = 5300 \text{ Å}$ and $\lambda_2 = 5700 \text{ Å}$ as relatively free of discrete emissions. The presence of a hypothetical emission of about $\lambda = 5700 \text{ Å}$ [6,7] cannot serve as an obstacle since, if it does exist and is not scattered, then the absolute intensity and the boundaries of its change must be small values (in the opposite case, it would undoubtedly have been already discovered), and it cannot substantially alter the intensity ratio for the sections we selected. If this emission is scattered, then it must be added to the components of the continuum.

Thus

$$j = \frac{i_{5700}^k}{i_{5300}^k}, \quad (1)$$

where i_{5700}^k and i_{5300}^k are the intensities of the integral continuum /7 per 1 Å.

Let us examine the literature concerning the continuum spectral distribution, characterizing them by the coefficient j . According to spectrographic observations in 1939, the average spectral distribution of the continuum was obtained [8] (meaning the integral continuum). The observations were conducted at a zenith distance of $z = 70^\circ$. The coefficient j , calculated by the given curve, is equal to 1.6. Variations in the continuum spectral distribution were not examined.

O. Struve, C. T. Elvey and F. E. Roach [9] consider that the color index of the night sky is equal to $+0.5^m$. They also state that a study conducted by Collins in the same observatory showed that the color index is equal to 0.6^m . Relative to the variations in this value, they drew the following conclusion: "This important astrophysical value is variable and changes in relation to the time of the observations and the sky range being examined". Unfortunately, according to the data given in [9], we cannot calculate the coefficient j .

The average spectral distribution of the integral continuum is given in [10] according to spectrographic observations in the range of the Pole ($z = 47^\circ$). The authors show that there are variations in the continuum spectral distribution in the short-wave range of the spectrum. The coefficient j , calculated according to the averaged curve, is equal to 1.05. The margin for changes in j for individual curves is 0.88-1.33.

A. V. Mironov [11] does not give the night sky continuum spectral distribution. But, from the graph which is given in his work and which is plotted according to observations in Abastumani, we

can see that the continuum spectral distribution in the section $\lambda\lambda$ 5300-6000 Å changes substantially during the course of the night. Seasonal variations can be seen to a lesser degree. There was a division made, obviously, between the atmospheric and extra-atmospheric components of the continuum, and the results described relate to the atmospheric component. The observations were conducted at the zenith by the electrophotometrical method during 1958 and 1959.

The average value of j for the atmospheric component of the continuum given in [12] is equal to 1.16. The margins for changes in j are not given. However, from the graphs given in this paper, we can see that j undergoes seasonal variations as well as variations during the course of a night. The observations were conducted by the electrophotometrical method at the zenith during 1957 and 1958. Calculations of the extra-atmospheric component were made according to [13].

The average and individual curves of the spectral distribution for the integral airglow continuum are given in [5], [14], and [16]. The spectrographical observations were conducted at a zenith distance of $z = 60^\circ$, directed toward the North. The coefficient j , calculated according to the average curves, is equal to 1.13. The limits for a change in j are 0.82-1.43. The curve for the continuum spectral distribution, considering the light scattered, is also given. The coefficient j , calculated for this curve, is equal to 1.22.

According to electrophotometrical observations, j changes within a range of 0.95-1.40 [17], and according to spectrographic observations, it changes from 0.6 to 2.6. The observations were conducted during the IGY at the zenith and at a zenith distance of $z = 60^\circ$, respectively.

V. M. Morozov [6, 18, 19] considers that there are no great variations in the continuum spectral distribution. Moreover, he shows that intensity ratio in λ 5890 Å and λ 5280 Å is much closer to that for the star class G2 than according to the data in [20]. Unfortunately, Morozov does not give the results of the measurements he made for the ratio i_{5700}^k/i_{5300}^k , i.e., direct measurements of the coefficient j .

According to the measurements made in Ashkhabad [21,22] for /8
the atmospheric component of the continuum, the average value for the coefficient j was equal to 1.44, and the ranges of its change were 0.97-1.59. The observations were conducted on a scanning electrophotometer [23] in 1962.

We could never draw any conclusions on the latitudinal or time functions (Table 1) from these data. However, we can conclude that: (1) the spectral distribution of the integral continuum and its atmospheric component differs from the spectral distribution for the

TABLE 1. SPECTRAL VARIATIONS IN

Author	Method	Continuum	Latitude of the Observation Site, <i>N</i>	Period of the Observation (Year)
H. W. Babcock, J. J. Johnson [8]	S	I	33°	1939
O. Struve, C. T. Elvey, F. E. Roach [9]	F	I	31	-
Z. V. Karyagina, L. N. Tulen- kova [10]	S	I	43	1957
L. M. Fishkova, G. V. Markova [12]	E	A	42	1957-1958
A. V. Mironov [11]	E	A	42	1957-1959
N. N. Shefov [5,14-16]	S	I	56	1957-1959
	S	I	56	1957-1959
V. I. Krassovsky [17]	S	I	56	1957-1959
	E	I	56	1957-1959
V. M. Morozov [6,18,19]	E	I	56	1957-1959
Yu. L. Truttse [21,22]	E	A	38	1962
K. U. Allen [24]				

Conditional Symbols: S - Spectrographical Observations;
 E - Electrophotometrical Observations;
 F - Photographical Observations with Filters;
 I - Integral Continuum;
 A - Atmospheric Component.

CONTINUUM ACCORDING TO VARIOUS AUTHORS

/9

Observed Range	$\bar{j} = \frac{i^k_{5700}}{i^k_{5300}}$	Variation Limits for j as a Percent of j	Comments
$z = 70^\circ$	1.6	-	The authors did not examine the variations.
Pole	-	-	Variations are given.
Same	1.05	-16-+27%	
Zenith	1.16	-	There are variations.
Same	-	-	Same.
$z = 60^\circ$	1.13	-28-+27%	Disregarding the light scattered.
$z = 60^\circ$	1.22	-33-+17%	Considering the light scattered.
$z = 60^\circ$	-	$\pm 62\%$	
Zenith	-	$\pm 19\%$	
Same	-	-	It is assumed that there are no variations, or else very small ones.
$z=10-70^\circ$	1.44	-23-+10%	
	1.02		Solar spectrum.

Sun (class G2); (2) the spectral distribution of the integral continuum and its atmospheric component undergoes significant variations. In order to explain the space-time characteristics for variations in the spectral distribution of the integral continuum and its atmospheric component, we conducted special observations.

OBSERVATIONS

The observations were conducted in the Astrophotometrics Laboratory of the Institute of Physics and Technology of the Academy of Sciences of the Turkmen S.S.R. in the town of Vannovskiy on a scanning electrophotometer. The intensities of the integral continuum were measured for the $\lambda\lambda$ 5300 Å and 5700 Å regions, which were separated by interference filters. The curves for the coefficient of penetration P of the filters and the discrete emissions incident in the range of filtration are shown in Figure 1.

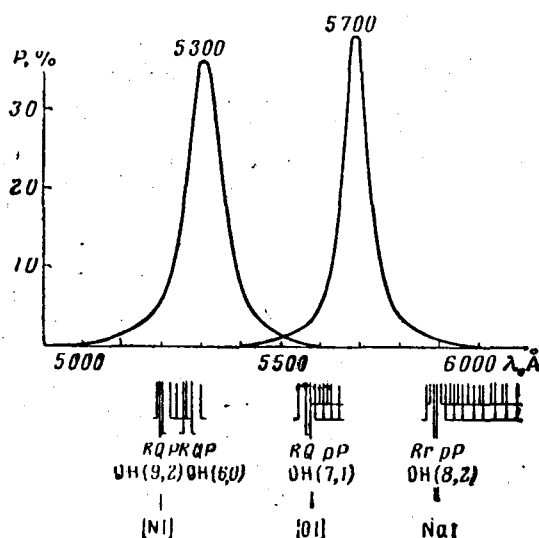


Fig. 1. Curves of Filtration.

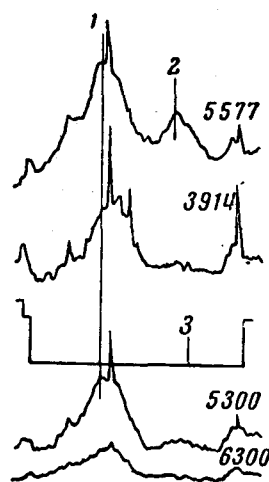


Fig. 2. Recording of the Emission Intensities in Various Filters. (1) Milky Way; (2) Local Increase in Emission Intensities for λ 5577 Å; (3) Photometer Orientation Point.

As we can see from Figure 1, the filter with λ 5300 Å partially penetrates the [NI] line and the OH (9.2) and (6.0) bands. The total intensity of these bands and of the line which is penetrated by the filter is about 1.6 Rayleighs. The data on the average intensity of the [NI] line and the OH (9.2) and (6.0) bands were taken according to [25,26]. The filter with λ 5700 Å partially penetrates the NaI doublet, the OH (7.1) and (8.2) bands, and the green oxygen line with λ 5577 Å. The total intensity for these lines and bands, which can be penetrated by the filter, is on the average about 17 /10 Rayleighs, or 18.3% of the average total intensity which can be penetrated by the filter, in measurements of the continuum. The

average intensity of the integral continuum was made equal to 2 Rayleighs per 1 Å [25,26]. The effective width of the band with total penetration (i.e., relative to 100% penetration) $\Delta\lambda$ of the filter with λ 5700 Å is equal to 38 Å. The data on the average intensity of the bands and lines were used according to [25,26]. The tests for their analysis were carefully considered.

The small variations in the [OI] intensity for λ 5577 Å do not entail any substantial errors for the determined ratio $j = i_{5700}^k / i_{5300}^k$, since even a change in the intensity I_{5577} by a factor of 1.5 on both sides changes j by $\pm 8\%$. Nevertheless, in order to regulate the intensities in the λ 5300 Å and 5700 Å regions parallel to these observations, we also conducted observations on a filter with 5577 Å in order to obtain the average emission intensity of the sky for [OI] with λ 5577 Å. It was rather easy to find the possible significant local changes in the intensity of the λ 5577 Å line on our recording, as we can see from Figure 2, and as can be calculated.

The scanning was made along a successive series of almucantars with $z = 10^\circ - 70^\circ$ for every 10° . The transition from one almucantar to another occurred at an azimuth $A = 0^\circ$. In order to regulate the sensitivity every 30 minutes, a calibrating device, in the form of a luminophore with radioactive connections, measured the sensitivity on all the channels. The dark current was also regulated every 30 minutes. Scanning along one almucantar took 2 min. 15 sec. Thus, the picture for distribution of the sky intensities in the spectral sections chosen was obtained in 16 minutes. In order to develop this, the nights of March 8-9, 9-10, 1962, were chosen. The selection was made according to the least "spottiness" for radiation of the [OI] λ 5577 Å line.

The ratio for $j = i_{5700}^k / i_{5300}^k$ was determined in the following way. We will present the intensity of the integral continuum which is recorded with a filter of λ 5300 Å by the following:

$$q_{5300} n_{5300} = i_{5300}^k \Delta\lambda_{5300}, \quad (2)$$

where q_{5300} is the coefficient of transition from the divisions of the calculated arrangement to the intensity in Rayleighs, and n_{5300} is the instrument's reading for the airglow.

In the same way, for the filter with λ 5700 Å we have:

$$q_{5700} n_{5700} = i_{5700}^k \Delta\lambda_{5700}. \quad (3)$$

Dividing (3) by (2) and substituting into the obtained result the value q and considering the fact that the solid angles were equal (during operation with λ 5300 Å and λ 5700 Å filters) we will obtain the final expression for j :

$$j = \frac{i_{5700}^*}{i_{5300}^*} \frac{n_{5300}^*}{n_{5700}^*} \frac{n_{5700}}{n_{5300}}, \quad (4)$$

where i_{5700}^*/i_{5300}^* is the ratio of intensities for the continuous spectrum per 1 Å in the $\lambda\lambda$ 5300 Å and 5700 Å regions for the star class G2, and n_{5300}^*/n_{5700}^* is the ratio of readings from the star class G2 for the same sections.

The ratio for i_{5700}^*/i_{5300}^* was taken according to [24]. The value for n_{5300}^*/n_{5700}^* was determined by direct measurements on the recorder. Since these ratios were measured not only by the G2 star class, we made a color test $\Delta(C)$

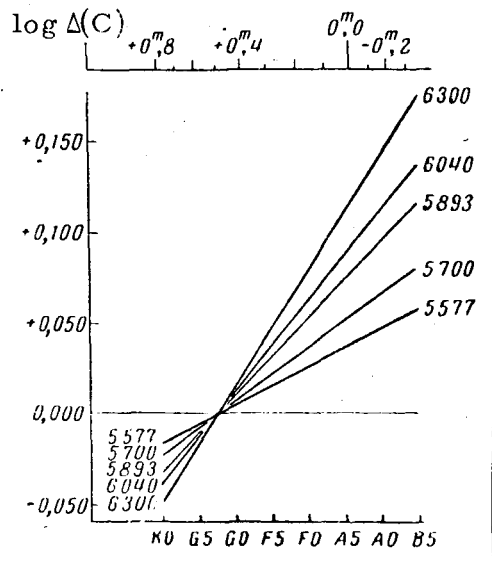


Fig. 3. Values for $\log \Delta(C)$ Versus the Color Index and the Spectral Class of the Star for Various Sections of the Spectrum.

for stars of other spectral classes. Since we used the energy distribution for the Solar spectrum [24], which differed insignificantly from the one in [27], and since we used regions with wavelengths that are not given in that paper, the tests for color were recalculated. The data on the color temperatures for various spectral star classes were taken from [24].

The data on the energy distribution in the equilibrium radiation spectrum were borrowed from the tables in [28]. The results obtained are shown in Table 2. For convenience in interpolating the tests for the color index C , the curves of the dependence of the logarithm of the test $\log \Delta(C)$ on the color index C or on the type of spectral class are shown in Figure 3. The value for $\log \Delta(C)$ must be added to the log-

TABLE 2. VALUE OF $\log \Delta(C)$, ADDED TO THE LOGARITHM OF THE PHOTOMETER READING ON STAR CLASSES FROM B TO K, FOR REDUCING IT TO THE READING ON THE G2 STAR CLASS

spectral class	color temp, °K	color index	$\lg \Delta(C)$					
			$\lambda 5300\text{Å}$	$\lambda 5577\text{Å}$	$\lambda 5700\text{Å}$	$\lambda 5893\text{Å}$	$\lambda 6040\text{Å}$	$\lambda 6300\text{Å}$
B 5	21 500	m -0,36	0,000	+0,057	+0,080	+0,125	+0,136	+0,178
A 0	15 400	-0,17	0,000	+0,050	+0,068	+0,095	+0,112	+0,148
A 5	11 500	+0,03	0,000	+0,037	+0,050	+0,072	+0,086	+0,111
F 0	9 100	+0,15	0,000	+0,026	+0,034	+0,050	+0,058	+0,079
F 5	7 600	+0,28	0,000	+0,013	+0,019	+0,029	+0,032	+0,044
G 0	6 700	+0,42	0,000	+0,005	+0,007	+0,009	+0,010	+0,012
G 2	6 400	+0,52	0,000	0,000	0,000	0,000	0,000	0,000
G 5	6 000	+0,58	0,000	-0,006	-0,009	-0,013	-0,016	-0,018
K 0	5 500	+0,77	0,000	-0,016	-0,024	-0,032	-0,041	-0,050

TABLE 3. VALUES FOR j ACCORDING TO OBSERVATIONS ON MARCH 9-10, 1962.
THE AVERAGE VALUE FOR j_N IS EQUAL TO 1.34.

z	$23^h 07^m$	$23^h 21^m$	$00^h 22^m$	$00^h 39^m$	$00^h 55^m$	$01^h 11^m$	$01^h 28^m$	$01^h 44^m$	$02^h 00^m$	$02^h 28^m$	$02^h 35^m$	$02^h 52^m$	$03^h 08^m$	$03^h 24^m$	$03^h 40^m$	$\bar{J} z$
$[40^\circ$	1,27	1,27	1,22	1,21	1,21	1,37	1,39	1,27	1,23	1,21	1,19	1,28	1,29	1,35	1,44	1,28
20	1,29	1,24	1,19	1,25	1,27	1,41	1,31	1,28	1,25	1,31	1,20	1,25	1,23	1,31	1,42	1,28
30	1,23	1,31	1,17	1,27	1,23	1,35	1,30	1,27	1,24	1,32	1,19	1,13	1,20	1,25	1,41	1,26
40	1,22	1,29	1,22	1,35	1,24	1,35	1,29	1,31	1,23	1,26	1,25	1,32	1,27	1,27	1,38	1,28
50	1,33	1,31	1,24	1,35	1,30	1,38	1,33	1,30	1,22	1,31	1,28	1,31	1,27	1,30	1,44	1,31
60	1,30	1,34	1,29	1,32	1,28	1,38	1,37	1,43	1,24	1,38	1,28	1,29	1,35	1,33	1,43	1,33
70	1,30	1,36	1,34	1,34	1,37	1,37	1,39	1,39	1,31	1,31	1,25	1,25	1,35	1,35	1,53	1,35
$\bar{I} t$	1,30	1,35	1,31	1,32	1,34	1,37	1,38	1,39	1,28	1,32	1,25	1,26	1,33	1,35	1,49	

TABLE 4. VALUES FOR j ACCORDING TO OBSERVATIONS ON MARCH 9-10, 1962.
THE AVERAGE VALUE FOR $\overline{j_N}$ IS EQUAL TO 1.46.

z	$23^h 10^m$	$23^h 33^m$	$00^h 23^m$	$00^h 37^m$	$00^h 53^m$	$01^h 08^m$	$01^h 23^m$	$01^h 36^m$	$01^h 52^m$	$02^h 20^m$	$02^h 34^m$	$02^h 49^m$	$03^h 03^m$	$03^h 17^m$	$03^h 34^m$	$\bar{z}$
10°	1,25	1,12	1,35	1,33	1,36	1,33	1,34	1,44	1,43	1,59	1,63	1,58	1,41	1,41	1,36	1,40
20	1,28	1,14	1,40	1,27	1,39	1,35	1,32	1,41	1,45	1,56	1,63	1,48	1,44	1,46	1,40	1,40
30	1,29	1,06	1,29	1,26	1,33	1,38	1,43	1,44	1,54	1,49	1,59	1,55	1,36	1,46	1,41	1,39
40	1,27	1,06	1,34	1,21	1,31	1,41	1,46	1,50	1,34	1,50	1,58	1,59	1,50	1,49	1,38	1,40
50	1,27	1,11	1,34	1,31	1,42	1,45	1,48	1,51	1,46	1,58	1,54	1,48	1,43	1,51	1,41	1,42
60	1,37	1,21	1,47	1,37	1,51	1,47	1,48	1,58	1,52	1,53	1,52	1,53	1,49	1,58	1,45	1,43
70	1,34	1,31	1,46	1,46	1,54	1,54	1,51	1,51	1,52	1,52	1,52	1,51	1,51	1,45	1,45	1,48
$\bar{z}$	1,33	1,26	1,44	1,42	1,51	1,51	1,50	1,52	1,50	1,53	1,52	1,52	1,49	1,48	1,44	

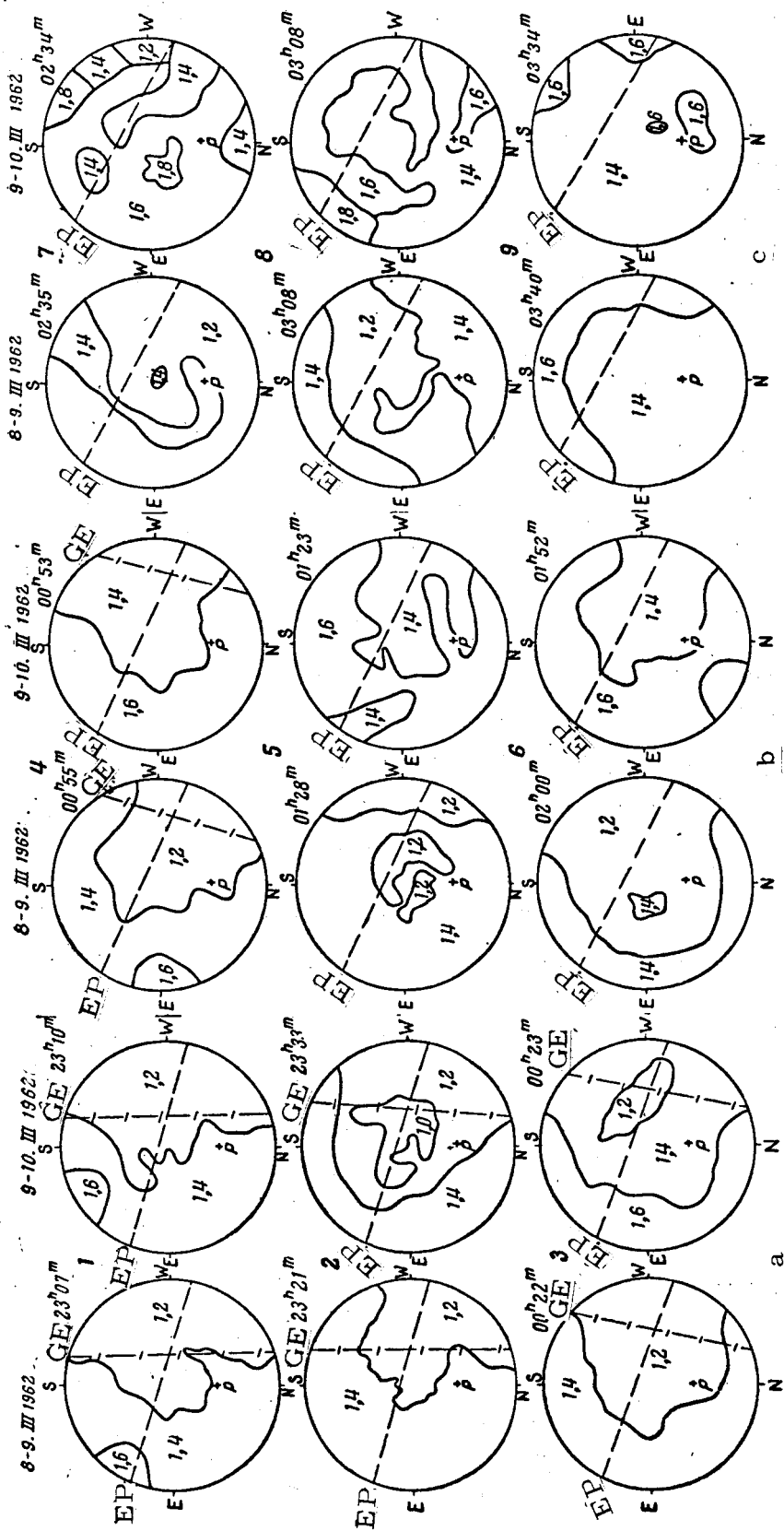


Fig. 4. Diagrams of the Spatial Distribution for the Continuum Intensities Ratio j in Spectral Regions $\lambda 5700 \text{ \AA}$ to $\lambda 5300 \text{ \AA}$. (a) Beginning of the Night; (b) Middle of the Night; (c) End of the Night.

arithm of the photometer reading on the stars of a certain spectral class in order to reduce this reading to the reading on the stars of the G2 spectral class.

Since the measurements in the filters were taken by various photometric channels whose sensitivity change independently, the average value obtained for n_{5300}^*/n_{5700}^* was multiplied by the coefficient

$$k = \frac{n_{5300}^{\text{cal}} \bar{n}_{5700}^{\text{cal}}}{n_{5700}^{\text{cal}} \bar{n}_{5300}^{\text{cal}}},$$

considering the relative change in sensitivity of the photometer channels for each moment, where n_{λ}^{cal} are the individual values for the readings on the calibrating device, and $\bar{n}_{\lambda}^{\text{cal}}$ are the average values for the readings on the calibrating devices per night.

RESULTS OBTAINED

As a result of the observations conducted, we obtained a large number of values for $j = i_{5700}^k / i_{5300}^k$ for various moments in time t , azimuths A , and zenith distances z . The values obtained for j are shown in Table 3 (March 8-9, 1962) and Table 4 (March 9-10, 1962), /14 where $\bar{j}_z$ is the average value for j at a given zenith distance, $\bar{j}_t$ is the average value for a given moment, and $\bar{j}_N$ is the average value per night. All the moments in time were given according to Ashkhabad Statute Time (Fourth Time Zone).

As we can see from the tables, the values of j for these nights are very different. Since the intervals for observations practically coincide for both nights, i.e., the extra-atmospheric component of their integral continuum is identical, it is natural to assume that the change occurred because of the atmospheric component of the

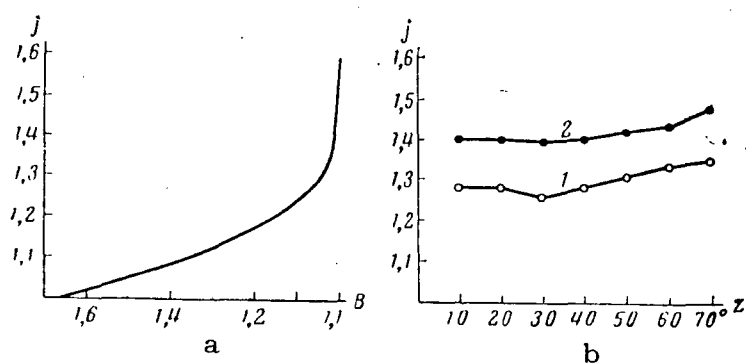


Fig. 5. The Value of j Versus the Selected Region of the Sky.
(a) Dependence on the Value of the Continuum Stellar Component;
(b) Dependence on the Zenith Distance. (1) March 8-9, 1962;
(2) March 9-10, 1962.

continuum. An examination of the diagrams for the spatial distribution of j , shown in Figure 4 a, b, c, results in a conclusion on the variations in the atmospheric component of the continuum. The diagrams are arranged in pairs for the nights of March 8-9, 9-10, 1962, for moments of time which coincide with a sufficient degree of accuracy. The "spotty" character of the distribution for j is immediately striking. This can be partially explained by the effect of a change in the value for the extra-atmospheric component of the continuum. Thus, in Diagrams 1-5 (Fig. 4 a, b), the value for j in the western part of the sky is greater than in the eastern. This can be explained by the effect of the Milky Way. If, at the beginning of the observation period, it were in the West (the position of the galactic equator, which subsequently left the field of vision, is plotted in Diagrams 1-4), then it would begin to approach the range being scanned from the East at the end of the observations.

Thus, in the range of the Milky Way (i.e., in the range where the extra-atmospheric component of the continuum reaches maximum values), the values for j are less than in other ranges of the sky. We can assume from this that the atmospheric component of the continuum is more "red" by its spectral distribution than the extra-atmospheric. Subsequently, if we construct a graph for the dependence of the value for j on the value for the extra-atmospheric component, we must obtain an increase in the mean value for j with a decrease in the extra-atmospheric component of the continuum.

In Figure 5 a, we find the graph for the mean value of $\bar{j}$ as a function of the value

$$B = \frac{n_{5300}}{n_{6300}^{\min}} = \frac{1+d}{1+d^{\min}},$$

which increases with a decrease in the number of extra-atmospheric components. The value for d is equal to the ratio of intensities of the atmospheric and extra-atmospheric components of the continuum, i.e., /15

$$d = \frac{i_a^k}{i_{\text{extra}}^k}.$$

We can see from the graph that, as the extra-atmospheric components increase, the mean values for $\bar{j}$, as we assumed, decrease, approaching the values which correspond to the G2 spectral class during observations in the brightest ranges of the Milky Way. A decrease in the number of extra-atmospheric components coincides with an increase in the value of j .

In order to clarify the question on which of the components of the integral continuum is more "red", we can also examine the dependence of the value for j on the zenith distance z . The average

intensity for the integral continuum $\bar{i}_z^k$ which is recorded by the photometer at a zenith distance z can be written rather accurately by the following expression:

$$\bar{i}_z^k = \bar{i}_{0a}^k (V p^{M_z} + \alpha_0) + \bar{i}_{0\text{extra}}^k (p^{M_z} + \alpha_\infty), \quad (6)$$

where $\bar{i}_{0a}^k$ is the average intensity of the atmospheric component in the zenith, $\bar{i}_{0\text{extra}}^k$ is the average intensity of the extra-atmospheric component beyond the boundaries of the atmosphere at a zenith distance z (it would be more accurate to use the mean value for the extra-atmospheric component in the sky, but the values for the extra-atmospheric component in the sky and along one almucantar practically coincide), $V(z, h, p)$ is the van Rayn function, α_0 is the value of the light scattered, produced by the atmospheric component which is expressed in fractions of $\bar{i}_{0a}^k$, α_∞ is the analogous value for $\bar{i}_{0\text{extra}}^k$, p is the coefficient of transparency of the atmosphere, and M_z is the mass of the air.

Since, with an increase in z , there is a decrease in the coefficient $p^{M_z} + \alpha_\infty$ and a decrease in $V p^{M_z} + \alpha_0$ [29-31], the ratio between the atmospheric $\bar{i}_a^k$ and extra-atmospheric $\bar{i}_{\text{extra}}^k$ components will change with an increase in z in favor of the extra-atmospheric component. There are three possible cases, in relation to this, for a change in the color of the integral continuum with an increase in z :

(1) The average atmospheric $\bar{i}_a^k$ and the average extra-atmospheric $\bar{i}_{\text{extra}}^k$ components have identical spectral distribution. In this case the color of the integral continuum will not change with a change in z (j is constant for all z 's).

(2) The average atmospheric component $\bar{i}_a^k$ is less "red" than the average extra-atmospheric component $\bar{i}_{\text{extra}}^k$. In this case the color of the continuum becomes less "red" with an increase in z , i.e., the value of j will decrease with an increase in z .

(3) The average atmospheric component $\bar{i}_a^k$ is more "red" than the average extra-atmospheric component $\bar{i}_{\text{extra}}^k$. In this case the color of the continuum becomes more "red" with an increase in z , i.e., the value of j will increase with an increase in z .

The dependence of $\bar{j}$ on z is shown in Figure 5 b. We can clearly see that the value for $\bar{j}$ increases with an increase in z . The numerical values on which the graph in Figure 5 b is constructed are given in the last column of Tables 3 and 4. The fact that the increase in j slows down somewhat, as we can clearly see both in the graph and in the tables, can be explained by the effect of the Milky Way (at the beginning of the observations, in scanning along the almucantar with $z = 30-70^\circ$, the Milky Way fell within the field of vision for the electrophotometer).

Thus an increase in j with an increase in z is one more in-

/16

dication that the atmospheric component of the integral continuum i_a^k is more "red" than its extra-atmospheric component i_{extra}^k .

However, the variations in the color of the integral continuum in the sky can never be explained only by the effect of the value and the spectral distribution of its extra-atmospheric component i_{extra}^k . We can see, from a comparison between the diagrams of distribution of j in the sky for the night of March 8 and the distribution of j at the same moments for the night of March 9, that they differ greatly from each other, despite the identical extra-atmospheric components (the coefficients of transparency of the atmosphere p_λ practically coincide for both nights). This difference can be seen very clearly in Diagrams 4 to 7 (Fig. 4 b, c). A possible explanation for this is the assumption of variations in the intensity of the atmospheric component of the continuum. However, since these variations for the longitude of the observation site (38°N) have rather limiting boundaries (the changes in intensity of radiation in the λ 5300 Å region for the observation nights are shown in Table 5), then we must assume that there are rather great variations in the spectral distribution of the atmospheric component [21, 32, 33]. This conclusion is substantiated by the fact that, in the green spots with high intensity, similar to those described previously [34, 35], there is often a uniform increase in the intensity of the continuum in the λ 5577 Å region with a practically invariable intensity in the continuum of λ 5300 Å. The emission intensities for [OI] λ 5577 Å were determined simultaneously with the aid of the scanning spectro-electrophotometer. The value of j for these sections of the spectrum increased up to a factor of 1.5 in comparison with its mean value. This phenomenon is described in detail in [35].

The changes in the spectral structure of the integral continuum occur not only from night to night, but also in the course of the night. The variations in the average values for the intensity for the green oxygen line I_{5577} (in relative units) is given in Figure 6. The variations in $\bar{j}_t$ for the nights of the observation are also given there. There is no apparent link between the character of the change in $\bar{j}_t$ and in I_{5577} . This serves as an indicator of a fairly correct calculation for the value of I_{5577} which is penetrated by the filter with λ 5700 Å.

TABLE 5. AVERAGE VALUES PER NIGHT FOR THE EMISSION INTENSITY IN THE λ 5300 Å REGION (INTENSITIES ARE GIVEN IN RELATIVE UNITS)

Date	z						
	10°	20°	30°	40°	50°	60°	70°
8-9 Mar. 1962	49,6	50,7	54,5	58,0	62,3	69,0	77,8
9-10 Mar. 1962	50,0	51,7	54,9	58,9	63,7	70,3	80,7

The spatial dimensions of the discontinuities in distribution of j in the sky are fairly great. This can obviously be explained by the fact that some authors [18], in observations at two points (zenith and pole), did not find any variations in the spectral structure of the continuum. Actually, from the 18 diagrams shown in Figure 4 a, b, c, j coincides for the pole and the zenith for 16 of them, and the difference for the remaining ones does not exceed 20%. This conformity is observed even more frequently for sites at a high latitude, i.e., as the pole approaches the zenith.

On the basis of the data examined, we can draw the following conclusions.

(1) The airglow integral continuum has two principal components: atmospheric i_a^k and extra-atmospheric i_{extra}^k . /17

(2) The average spectral distribution of the integral continuum in the region of the spectrum being studied does not coincide with the spectral distribution for the G2 star class, but corresponds to the distribution for stars of later classes.

(3) The atmospheric component i_a^k of the integral continuum undergoes variations in intensity and in spectral distribution.

(4) The spectral distribution for the atmospheric i_a^k and extra-atmospheric i_{extra}^k components of the integral continuum is not uniform. The atmospheric component is, on the average, more "red".

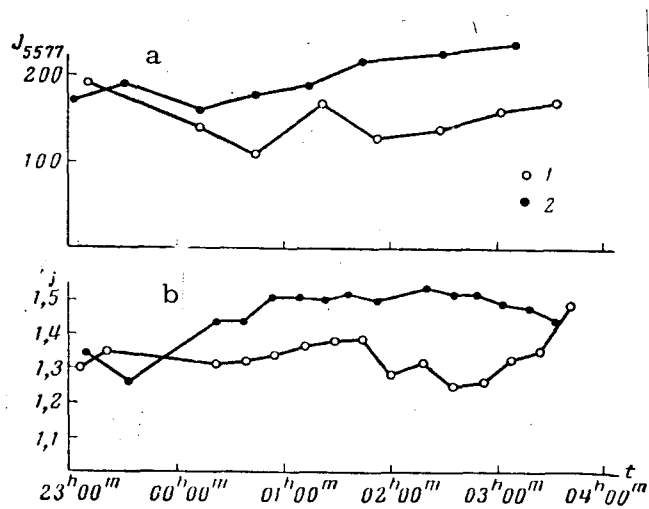


Fig. 6. Variations in the Average Intensities in the Sky for the Green Line (a) and the Spectral Distribution of the Continuum (b) in the Course of a Night. (1) March 8-9, 1962; (2) March 9-10, 1962.

(5) The ratio between the atmospheric i_a^k and extra-atmospheric i_{extra}^k components does not remain constant, but is a function of the equatorial (α, δ) and horizontal (A, z) coordinates of the sky range being observed, and also of the moment of observation t .

(6) On the basis of conclusions (3) to (5) and the data in [37], we can assume that there are spatial and time variations of the integral continuum spectral distribution. The observations conducted confirm this assumption. The limits of the variations in $j = i_{5700}^k / i_{5300}^k$ for two nights of observations was -24% and +9%. The linear di-

mensions for the discontinuities are great (on the average, they are greater than 200 km).

(7) The method used previously for determining the intensities of discrete emissions in electrophotometrical observations by calculating the intensity of the continuum from one spectral region to another, obviously, cannot be used.

REFERENCES

1. Barbier, D.: I. Le spectre du ciel nocturne (The Spectrum of the Night Sky), Ann. Astrophys., Vol. 10, No. 1, pp. 47-66, 1947. /18
2. Barbier, D.: II. Le spectre du ciel nocturne (The Spectrum of the Night Sky), Ann. Astrophys., Vol. 10, No. 2, pp. 141-157, 1947.
3. Chamberlain, J. W. and N. J. Oliver: Stellar Absorption Lines in Night Sky Spectra, Astrophys. J., Vol. 118, No. 2, pp. 197-199, 1953.
4. Meinel, A. B.: Origin of the Continuum in the Night-Sky Spectrum, Astrophys. J., Vol. 118, No. 2, pp. 200-204, 1953.
5. Shefov, N. N.: Intensivnosti nekotorykh emissiy nochnogo neba, Sb.: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Intensities of Some Emissions of the Night Sky. Collection: Spectral, Electro-photometrical, and Radar Studies on Aurorae and Airglow), No. 2-3, seriya "Rezultaty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 57-59, 1960.
6. Morozov, V. M.: O nepostoyanstve sostava kontinuum v svechenii nochnogo neba (The Variability of the Structure of the Continuum in Airglow), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 4, pp. 573-576, 1962.
7. Barbier, D.: Analyse du spectre du spectre du ciel nocturne (Analysis of the Night-Sky Spectrum), Ann. Géophys., Vol. 11, No. 2-4, pp. 181-208, 1955.
8. Babcock, H. W. and J. J. Johnson: A Spectrophotometric Study of the Light of the Night-Sky, Astrophys. J., Vol. 94, No. 2, pp. 271-275, 1941.
9. Struve, O., C. T. Elvey and F. E. Roach: Reflection Nebulae, Astrophys. J., Vol. 84, No. 2, pp. 219-228, 1936.
10. Karyagina, Z. V. and L. N. Tulenkova: Spektrofotometricheskoye issledovaniye nepreryvnogo i emissionnogo spektra nochnogo neba v vizual'noy oblasti spektra (Spectrophotometrical Studies on the Continuous and Emission Night-Sky Spectrum in the Visual Range of the Spectrum), Izvest. Astrofiz. Instit. Akad. Nauk Kazanskiy S.S.R., Vol. 9, pp. 86-95, 1959.
11. Mironov, A. V.: Nekotoryye rezul'taty obrabotki elektrofotometricheskikh nablyudeniy izlucheniya nochnogo neba, Sb.: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Some Results of Developing Electrophotometrical Observations of the Night-Sky Emission. Collection: Spectral,

- Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 6, seriya "Rezultaty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 12-16, 1961.
12. Fishkova, L. M. and G. V. Markova: Nekotoryye rezultaty elektrofotometricheskikh i spektrograficheskikh nablyudeniy svecheniya nochnogo neba. Ab.: Spektral'nyye, elektroforometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Some Results of Electrophotometrical and Spectrographical Observations of the Airglow. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 2-3, seriya "Rezultaty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 49-56, 1960.
 13. Barbier, D., J. Dufay and D. Williams: Recherches sur l'émission de la raie verte de la lumière du ciel nocturne (Studies on the Emission of the Green Range in Airglow), Ann. Astrophys., Vol. 14, No. 4, pp. 399-437, 1951.
 14. Shefov, N. N.: Intensivnosti nekotorykh emissiy sumerechnogo i nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Intensities of Emissions of the Twilight and Night Sky. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 1, seriya "Rezultaty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 25-29, 1959.
 15. Shefov, N. N.: Nepreryvnyy spektr v svechenii nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Continuous Spectrum in the Airglow. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 5, seriya "Rezultaty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 39-41, 1961.
 16. Shefov, N. N.: Zamecheniya po povodu nekotorykh vyvodov V. M. Morozova o kontinuumе v izluchenii nochnogo neba (Comments Concerning Some of V. M. Morozov's Conclusions on the Continuum in the Night-Sky Emission), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1895-1897, 1961.
 17. Krassovskiy, V. I.: Pis'mo v redaktsiyu (Letter to the Editor), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1898-1900, 1961.
 18. Morozov, V. M.: Nekotoryye fotometricheskiye dannyye o kontinuumе v svechenii nochnogo neba (Some Photometrical Data on the Continuum in the Airglow), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 188-1894, 1961.
 19. Morozov, V. M.: Nekotoryye osobennosti emissii [OI] λ 5577 Å i kontinuumа svechenii nochnogo neba (Some Features of the [OI] λ 5577 Å Emission and the Airglow Continuum), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 10, pp. 1446-1449, 1962.
 20. Barbier, D. and J. Glaume: Corrélations entre les intensités des diverses radiations de la luminescence atmosphérique nocturne (Correlations among the Intensities of Various

- Radiations of the Atmospheric Night Luminescence), Ann. Géophys., Vol. 16, No. 1, pp. 56-87, 1960.
21. Truttse, Yu. L.: Spektral'noye raspredeleniye vneatmosfernoy i atmosfernoy sostavlyayushchikh kontinuumu v svechenii nochnogo neba. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Spectral Distribution of the Extra-Atmospheric and Atmospheric Components of the Continuum in Airglow. Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 5-7, 1963.
 22. Truttse, Yu. L.: Izmereniya fona pri fotoelektricheskikh nablyudeniyakh emisii [OI] λ 5577 Å. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Measurements of the Background in Photoelectric Observations of the [OI] λ 5577 Å Emission. Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 8-12, 1963.
 23. Dzhordzhio, N. V.: Avtomaticheskii skaniruyushchiy fotometr (Automatic Scanning Photometer), Geomagnetizm i aeronomiya, Vol. 1, No. 6, pp. 1005-1008, 1961.
 24. Allen, K. U.: Astrofizicheskiye velichiny (Astrophysical Values), Foreign Lit. Press, Moscow, 1960.
 25. Atlas spektra izlucheniya nochnogo neba λ 3000-12400 Å (Atlas of the Spectrum of Night-Sky Radiation in λ 3000-12400 Å. Instit. Fiz. Atmosfery Akad. Nauk S.S.S.R., Moscow, 1962.
 26. Krassovsky, V. I., N. N. Shefov and V. I. Yarin: Atlas of the Airglow Spectrum 3000-12400 Å. Planet. Space Sci., Vol. 9, No. 12, pp. 883-915, 1962.
 27. Roach, F. E.: Manual for Photometric Observations of the Airglow during the IGY. Rep. Natl. Bureau Standards, No. 5006, pp. 1-33, 1956.
 28. Apanasevich, P. A. and V. S. Ayzenshtadt: Tablitsy raspredeleniya energii i fotonov v spektre ravnovesnogo izlucheniya (Tables for the Energy and Photon Distribution in the Equilibrium Radiation Spectrum), Izdat. Akad. Nauk Bolgarskiy S.S.R., Minsk, 1961. /19
 29. Ashburn, E. V.: The Effect of Rayleigh Scattering and Ground Reflection upon the Determination of the Height of the Night Airglow, J. Atm. Terrest. Phys., Vol. 5, No. 2, pp. 83-91, 1954.
 30. Fesekov, V. G.: Meteornaya materiya v mezhplanetnom prostranstve (Meteor Matter in Interplanetary Space), Izdat. Akad. Nauk S.S.S.R., 1947.
 31. Chuvayev, K. K.: O razdelenii svecheniya nochnogo neba na sostavlyayushchiye (Dividing the Airglow into its Components), Astron. Zhur., Vol. 38, No. 4, pp. 692-705, 1961.
 32. Fishkova, L. M.: Nekotoryye rezul'taty elektrofotometricheskikh nablyudeniy emissiy OI, NaI, OH i nepreryvnogo fona v svechenii nochnogo neba (Some Results of Observations on OI, NaI, and OH Emissions and the Continuous Background in the Airglow), Byull. Abastum. Astrofiz. Observ., No. 24, pp. 161-173, 1959.
 33. Chuvayev, K. K.: Elektrofotometricheskiye issledovaniya svecheniya nochnogo neba v neskol'kikh oblastyakh spektra (Elec-

- trophotometrical Studies of the Airglow in Several Spectral Ranges), Izvest. Krymsk. Astrofiz. Observ., Vol. 10, pp. 54-73, 1953.
34. Truttse, Yu. L.: Anomalous Rise in the Intensity of the Atmosphere's Natural Glow in the λ 5577 Å Region. Planet. Space Sci., Vol. 9, No. 12, p. 993, 1962.
 35. Truttse, Yu. L.: Anomal'noye povysheniye intensivnosti sobstvennogo svecheniya atmosfery na uchastke λ 5577 Å. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Anomalous Rise in the Intensity of the Atmosphere's Natural Glow in the λ 5577 Å Region. Collection: Aurorae and Airglow), No. 10, seriya "Rezultaty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 13-14, 1963.
 36. Truttse, Yu. L.: Prostranstvennyye variatsii intensivnosti kislorodnykh liniy (Spatial Variations of the Oxygen Line Intensities), This Collection, p. 51.
 37. Roach, F. E. and L. R. Megill: Integrated Starlight over the Sky, Astrophys. J., Vol. 133, No. 1, pp. 228-242, 1961.

THE SEPARATION OF THE AIRGLOW CONTINUUM COMPONENTS

A. V. Migulin

ABSTRACT: The intensity and spectral distribution of the integral continuum and of its atmospheric component do not remain constant in time and space. The intensities of the green line and of the atmospheric component of the continuum near λ 5577 Å do not correlate. The transparency of the atmosphere was determined according to the zenith distance of the continuum stellar component intensity.

In the green-yellow range of the airglow spectrum, a large amount of the energy is in the continuous background (the continuum). /20
This continuum is a result of a combination of several components: (1) stellar light, (2) zodiacal light, (3) natural luminescence of the atmosphere, (4) scattered light from all the enumerated sources. The amount introduced by each component can change in time and in space. The third component is particularly variable.

In order to calculate the background by measurements in photometers with interference filters of any emission intensities, we considered in a number of studies that the energy distribution in the continuum corresponds to the G2 spectral star class. However, according to the results of some authors [1-3], the spectral distribution in the continuum differs from G2 in the redder part of the spectrum. If this is actually so, then the measured intensities for the [OI] 5577 line, for example, are too high.

It is interesting to note that the existence of the natural luminescence of the atmosphere in a continuous background was described in [4] from the condition for correlation of the green line with the continuous background. There is no single opinion at the present on the existence of such a correlation. According to recent data [5], it is more probable that there are two components in the continuous background of the natural atmospheric luminescence: one correlating with [OI] 5577, and one which does not correlate.

The natural atmospheric radiation is taken from the summary continuum by calculating all its remaining constituent components. Thus the continuum is determined by the depth of the Fraunhofer lines in [6]. According to the given computations, there is no atmospheric component for the background in the 4300 Å range. In [7]

it was found that 30% of all the continuum brightness is in the amount of natural atmospheric luminescence, 50% in the stellar component, and 20% in the zodiacal light. The author showed that the scattering can be rather accurately calculated by the Chandrasekar equations which were constructed for Rayleigh scattering.

The original experimental material in this paper was obtained on a high-speed photoelectrical spectrometer DFS-14 [8]. The material obtained consists of records of the airglow spectrum (Fig. 1) in the range from 3800 to 6000 Å. For each zenith angle, the pairs of records with various azimuths were obtained. At one zenith distance, the instrument was directed toward the range of the Milky Way and that range of the sky with a small number of stars. Under these circumstances, the region of the sky which is free of stars brighter than $\sim 5^m$ was chosen in both cases with the aid of an optical viewfinder. Such a selection for observation points allows us immediately to isolate the stellar background component, on the assumption that all the other background components will be equal at the two points with identical values for the zenith angles and with slightly differing azimuths. This is true for scattered light and, approximately, for zodiacal light, since the observation points were taken far from the ecliptic. For the atmospheric background component, generally speaking, this is not true, but the semistatic method for development applied in this study allows us to disregard to a great degree the effect of this non-uniformity. /21

The basis for the method used lies in the construction of a Bouguer line according to the experimental data. The regular Bouguer line is the graph for the logarithm of the luminary brightness versus the mass of the air, which is determined by the zenith angle of observation for this luminary. In this case, instead of a localized luminary, we take the spatial source which is equal to 100 eV 10^m per 1 kV degree. We can determine the transparency of the atmosphere, the losses in absorption, and the sensitivity of the recorder in the selected wavelengths by the Bouguer line.

The measured intensity of the background for any zenith angle is expressed by the following equation:

$$J_{ba}(z) = (J_a + J_{st} + J_{zod})P^M(z) + J_{scatt} \quad (1)$$

where J_a , J_{st} , and J_{zod} are the intensities of the atmospheric, stellar, and zodiacal background components; J_{scatt} is the brightness of the scattered atmospheric and stellar light incident on the recorder; P is the coefficient of transparency of the atmosphere; $M(z)$ is the mass of the air at the given zenith angle of observation. For each pair of points, for $\lambda = 5300$ Å as well as for $\lambda = 5577$ Å, we can obtain the expression,

$$\Delta J_{ba} = \Delta J_{st} P^M, \quad (2)$$

where ΔJ_{st} is the difference in intensities for the stellar background component at the two points of one pair, and ΔJ_{st} is expressed, according to Roach's tables [9], by the number of stars 10^m per 1 kV degree. After normalization, i.e., reducing the intensities to the standard source in 100 eV 10^m per 1 kV degree and taking the logarithms for (2), we obtain:

$$\log J_{100}(z) = \log J_{100}^0 + M(z) \cdot \lg P, \quad (3)$$

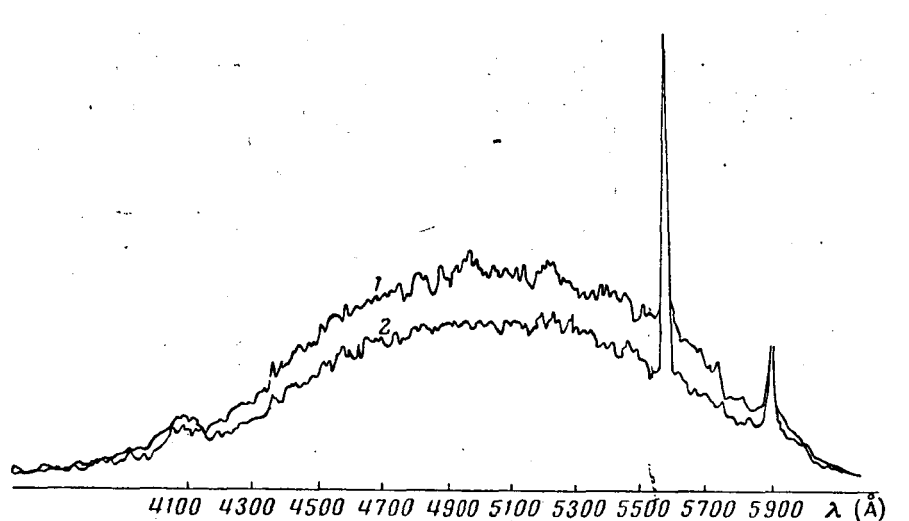


Fig. 1. Records of the Night Sky Spectrum, Obtained on February 2, 1962, at a Zenith Angle of Observation $z = 35^\circ$. (1) The Spectrum Coincides with the Directionality of the Instrument Toward the Milky Way; (2) Toward the Range with a Small Number of Stars.

where J_{100}^0 is the intensity which will be recorded from the source in 100 eV 10^m per 1 kV degree in the absence of absorption in the atmosphere, and $J_{100}(z)$ is the intensity which is recorded from the source in 100 eV 10^m per 1 kV degree at a given zenith observational angle. /22

Subsequently, according to the method of least squares, we find the Bouguer lines for two values of λ which are constructed for the spatial source with 100 eV 10^m per 1 kV degree. The lines are shown in Figures 2 and 3. We will determine the transparency coefficients P_1 and P_2 by the slope of the lines:

$$\begin{aligned} P_1 &= 0.53 \text{ for } \lambda = 5300 \text{ Å} \\ P_2 &= 0.54 \text{ for } \lambda = 5577 \text{ Å}. \end{aligned}$$

Using the values for J_{100}^0 obtained from the graphs, we can calculate the sensitivity of the instrument at these wavelengths. In calculating the sensitivity we assume that the spectral distribution in the stellar background of the selected regions of the sky corresponds to G2. In the range with $\lambda = 5577 \text{ Å}$, the sensitivity of the instrument is $S = 0.040 \text{ R/Å}$ per 1 mm of the potentiometer scale, and in the range with $\lambda = 5300 \text{ Å}$, $S = 0.025 \text{ R/Å mm}$.

Absolute calibration carried out subsequently in the instrument for the light of the Moon gave values for the sensitivity which were close to those values. In separating the components, the zodiacal light was not accounted for, since the observation points were far from the ecliptic.

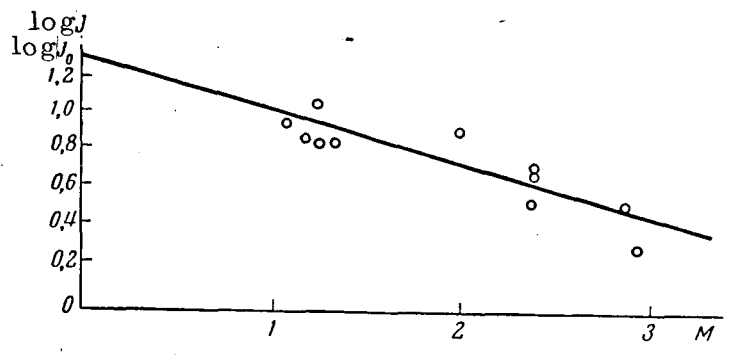


Fig. 2. Bouguer Line for Determining the Transparency Coefficient at $\lambda = 5300 \text{ \AA}$.

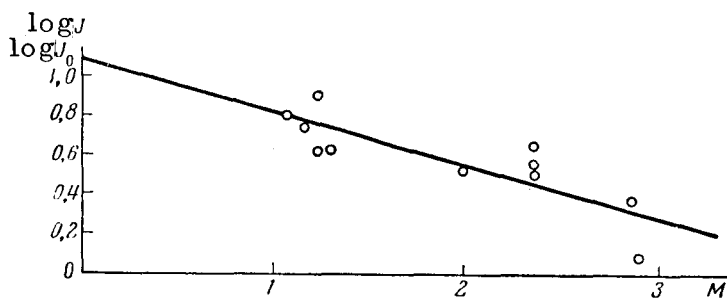


Fig. 3. Bouguer Line for Determining the Transparency Coefficient at $\lambda = 5577 \text{ \AA}$.

During further development, the stellar background component was considered, and the data were modified for absorption. These operations were made by using the Bouguer line.

Then, for convenience in comparing the results, all the brightnesses were reduced to the zenith with the aid of the van Rayne function. The height of the luminous layer was considered to be equal to 100 km for all three emissions (the background and the line at $\lambda = 5577 \text{ \AA}$, the background at $\lambda = 5300 \text{ \AA}$). The final developmental stage was to calculate the scattered light and the light which was reflected from the surface of the Earth covered with snow. From the transparency coefficient obtained P , we can find the optical thickness τ_0 of the atmosphere at the zenith, since $P = e^{-\tau_0}$. Tables giving the brightness of the scattered light as a function of the optical thickness τ_0 , the height of the luminous layer (h),

the zenith distance z , and the albedo of the Earth's surface are shown in [10]. In this case, $\tau_0 = 0.5$ for $\lambda = 5300 \text{ \AA}$ as well as for $\lambda = 5577 \text{ \AA}$, the albedo is equal to 0.8, $h = 100 \text{ km}$ in calculating the scattered atmospheric light, and $h = \infty$ in calculating the scattered stellar light. In calculating the second component of the scattered light, we assumed that the stellar sky shines uniformly with the brightness of $100 \text{ eV } 10^m$ per 1 kv degree .

As a result of this development, we obtained the intensity in Rayleighs for the $\lambda = 5577 \text{ \AA}$ line, the background near $\lambda = 5577 \text{ \AA}$, and the background near $\lambda = 5300 \text{ \AA}$. The average line intensity for a given night was equal to 80 Rayleighs. The average intensity of the atmospheric background component was equal to 2 Rayleighs/ $\text{\AA}$ for $\lambda = 5300 \text{ \AA}$, and 2.7 Rayleighs/ $\text{\AA}$ for $\lambda = 5577 \text{ \AA}$. The ratio for the

TABLE 1. ABSOLUTE AND RELATIVE INTENSITIES FOR THE $\lambda = 5577 \text{ \AA}$ EMISSION AND THE CONTINUUM ON FEBRUARY 1-2, 1962.

measurement number	Galactic coord.		no. of 10 ^m in 1 kv deg	natural extra-atmos- pheric brightness			relative brightness				
	l	b		line 5577 A	back- ground 5700Å	back- ground 5300Å	$J_{\lambda 5577}/$ $J_{ba 5577}$	$J_{\lambda 5577}/$ $J_{ba 5300}$	$J_{\lambda 5577}/$ $J_{ba 5300}$		
							R	R/A	cor- rected	cor- rected	observed
1	48,5	26°	99	116	2,8	2,3	41	1,2	1,2		
2	51	-1,8	419	117	2,7	2,1	43	1,3	1,1		
3	54	25,5	86	110	2,5	2,0	44	1,3	1,0		
4	57,5	-2,6	367	104	2,7	1,8	38	1,5	1,2		
5	50,5	22	101	93	2,3	1,6	40	2,4	1,3		
6	64,5	-5,5	282	77	2,7	2,0	28	1,4	1,2		
7	156	20	96	54	2,4	2,0	22	1,2	1,1		
8	154,5	7,5	167	53	2,5	1,9	21	1,3	1,1		
9	135,5	21	74	41	2,3	1,7	18	1,4	1,2		
10	139	3,5	167	52	2,5	1,5	21	1,7	1,4		
11	145	28	61	53	2,4	1,3	22	1,8	1,1		
12	78,5	-5	201	83	3,0	2,2	28	1,4	1,2		
13	96	2,5	149	70	3,1	2,2	23	1,4	1,3		
14	87,5	12	78	72	3,1	2,2	23	1,4	1,3		
15	73	-1	304	141	3,3	2,2	41	1,5	1,3		
16	102,5	22,5	67	128	3,2	2,2	40	1,5	1,3		
17	193	6,5	193	96	3,5	2,6	27	1,3	1,3		
18	162,5	18,5	92	110	3,4	2,6	32	1,3	1,3		
19	136	6	158	76	2,5	2,1	30	1,2	1,1		
20	170,5	29,5	62	69	2,7	2,1	25	1,3	1,2		
21	137,5	8,5	226	82	2,5	1,6	32	1,6	1,3		
22	94,5	22,5	70	88	2,1	1,8	42	1,2	1,1		
23	127,5	43,5	54	58	2,2	1,6	26	1,4	1,3		
24	89	27	58	70	2,1	1,6	33	1,3	1,2		
25	89	25	61	64	2,1	1,6	30	1,3	1,2		

values characterizing the energy distribution in the background was equal to 1.4. The analogous spectral distribution for these two wavelengths was obtained in [3] in a somewhat different way. The absolute values for the continuum intensity conform with the results of most of the researchers.

The spectral energy distribution in the total continuum was studied according to the direct results of the observation. We can see from Table 1 that the background intensity ratio for these two wavelengths is not constant at all the observational points, and it varies from 1.0 to 1.4. Therefore, calculating the green line intensity by observations with filters, on the premise that the energy distribution in the continuum corresponds to G2, may be invalid. Thus, with a filter having a penetration range of about 100 Å and with an intensity ratio equal to 1.4, the line intensity is on the average 50 Rayleighs too high, while 70 Rayleighs is about 25% of the average annual line intensity.

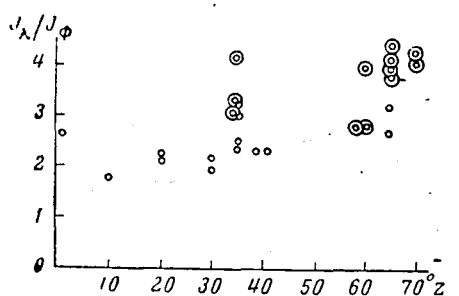


Fig. 4. Dependence of the Ratio of Modified Values for the Intensities J_λ for the Green Line to J_{ba} for the Background at the Same Value of $\lambda = 5577$ Å. The Points Corresponding to the Northern Observational Direction are Given by the Circles.

One of the reasons for the variability in the integral continuum may be the irregularity of the stellar background component distribution in the sky. The ratio between the green line intensity and the background at the same wavelength was also variable. We can isolate the range in the north-west where this ratio is increased (Fig. 4). No aurora was observed that night ($K = 2$).

On the basis of the results obtained, we can draw the following conclusions:

- (1) The energy distribution in the integral background as well as in the atmospheric background component does not remain constant in time and space.
- (2) The intensities of the green line and of the atmospheric background component at the same wavelength do not correlate, which could be caused by various excitation mechanisms.
- (3) The stellar component of the continuous background is a greater contribution to the λ 5300 Å range of the continuum than to the λ 5600 Å range.
- (4) A new method for developing the experimental data is presented in this paper. This method provides for calculating the transparency coefficient without making supplementary measurements.

The method is convenient for separating the atmospheric background component from the total continuum.

The author is very grateful to O. L. Baysberg for contributing a large amount of the experimental material and for his constant attention to the study.

REFERENCES

1. Chuvayev, K. K.: Elektrofotometricheskiye issledovaniya svecheniya nochnogo neba v neskol'kikh oblastyakh spektra (Electrophotometrical Studies of the Airglow in Several Spectral Ranges), Izvest. Kr. Astr. Observ., Vol. 10, pp. 54-73, 1953.
2. Shefov, N. N.: Nepreryvnyy spektr v svechenii nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Continuous Spectrum in the Airglow. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 5, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 42-43, 1961.
3. Truttse, Yu. L.: Spektral'noye raspredeleniye vneatmosfernoy i atmosfernoy sostavlyayushchikh kontinuumov v svechenii nochnogo neba. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Spectral Distribution of the Extra-Atmospheric and Atmospheric Continuum Components in the Airglow. Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 5-7, 1963. /25
4. Barbier, D., J. Dufay and D. Williams: Recherches sur l'émission de la raie verte de la lumière du ciel nocturne (Studies on the Green Range Emission for the Airglow). Ann. Astrophys., Vol. 14, No. 4, pp. 399-437, 1951.
5. Okuda, M.: A Study of Excitation Processes in Airglow. The Sci. Reports of the Tôhoky Univ., 5th Series, Geophysics, Vol. 14, No. 1, pp. 9-26, 1962.
6. Ingham, M. E.: The Nightglow Spectrum. I $\lambda\lambda$ 3700-4650 Å. Monthly Notices, Roy. Astron. Soc., Vol. 124, No. 6, pp. 505-522, 1962.
7. Chuvayev, K. K.: O razdelenii svecheniya nochnogo neba na sostavlyayushchiye (Dividing the Airglow into Its Components). Astron. Zhur., Vol. 38, No. 4, pp. 692-705, 1961.
8. Baysberg, O. L.: Nablyudeniya spektrov polyarnykh siyaniy s fotoelektricheskim spektrometrom (Observations of Aurorae with a Photoelectric Spectrometer). Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 8, pp. 1277-1278, 1960.
9. Roach, R. E., and L. R. Megill: Integrated Starlight over the Sky. Ap. J., Vol. 133, No. 1, pp. 228-242, 1961.
10. Ashburn, E. V.: The Effect of Rayleigh Scattering and Ground Reflection upon the Determination of the Height of the Night Airglow. J. Atm. and Terrest. Phys., Vol. 5, No. 2, pp. 83-91, 1954.

ABSOLUTE MEASUREMENTS OF THE AIRGLOW CONTINUUM

L. M. Gindilis

ABSTRACT: Absolute measurements of the airglow continuum in the 4200-6500 Å region were made. The intensity of the continuum changes from 0.8 to 1.9 R/Å and averages 1.5 R/Å. Energy distribution in the night sky continuous spectrum bears no resemblance to that in the spectrum of the Sun and the stars. The shape of the energy distribution curve is determined by the presence of a continuous emission.

The problem of the changes in the continuum spectral content is discussed. The relative intensity of the continuum J_{5577}/J_{5280} changes from 1.11 to 1.73 and averages 1.34. The relative intensity J_{5890}/J_{5280} changes from 1.11 to 2.70 and averages 1.54.

Diurnal variations of the continuum intensity are pointed out.

INSTRUMENT, METHOD, AND MATERIALS

Spectral observations of the airglow near the anthelion point /26
were made during the International Geophysical Year with the aim of studying the nature of the counterflow.

A transmission nebular spectrograph with little dispersion of the Pariyskiy system was used. The instrument, mounted in a parallactic arrangement, has an averaging angle of 1 kV degree, a relative lens opening of 1:0.7, and dispersion of about 2000 Å/mm for λ 5500 Å. The resolving power for the operating aperture width of 4.0 mm is characterized by the following values for the semiwidth $\Delta\lambda$ of the instrumental profile, in Å:

λ	4000	4500	5000	5500	6000	6500
$\Delta\lambda$	34	54	81	113	150	200

Because of the great transmission and the little dispersion of the spectrograph of the negative with a rather solid density in the continuous spectrum, we could obtain 30 minutes of exposure on Kodak 0aF plates.

TABLE 1. DESCRIPTION OF THE MATERIALS OBTAINED

Measure- ment Number		Date	U. T.	E						W						g								
				z	α	δ	λ	β	l	b	z	α	δ	λ	β	l	b	z	α	δ	λ	β	l	b
1	23.IX 1957	17 ^h 24 ^m	49°	1 ^h 16 ^m	— 7°	+15°	—13°	—67°	—67°	49°	22 ^h 46 ^m	+ 7°	—14°	+14°	+48°	—45°	46°	0 ^h 01 ^m	0°	0°	0°	+70°	—60°	
2	23.IX 1957	18 44	46	1 21	0	+19	— 8	—69	—60	46	22 41	0	—18	+ 8	+40	—50	43	0 01	0	0	0	+70	—60	
3	23.IX 1957	19 24	47	1 19	+ 4	+20	— 4	—72	—56	47	22 42	— 3	—19	+ 4	+36	—52	44	0 01	0	0	0	+70	—60	
4	24.IX 1957	17 09	50	1 19	— 6	+16	—13	—66	—61	50	22 51	+ 7	—13	+13	+49	—46	47	0 05	+ 1	+ 1	0	+72	—59	
5	24.IX 1957	18 44	46	1 25	+ 1	+20	— 8	—67	—59	46	22 45	+ 1	—17	+ 8	+41	—50	42	0 05	+ 1	+ 1	0	+72	—59	
6	27.IX 1957	17 26	47	1 32	+ 9	+24	— 1	—69	—51	47	23 01	— 5	—16	+ 1	+40	—57	43	0 16	+ 2	+ 4	0	+78	—59	
7	27.IX 1957	20 38	51	1 28	+11	+24	+ 2	—72	—49	51	23 05	— 8	—16	— 2	+52	—60	48	0 16	+ 2	+ 4	0	+78	—59	
8	30.IX 1957	18 42	44	1 47	+ 3	+26	— 8	—60	—55	44	23 07	+ 3	—11	+ 8	+50	—52	40	0 27	+ 3	+ 7	0	+84	—59	
9	30.IX 1957	19 42	46	1 45	+ 8	+27	— 2	—64	—51	46	23 10	— 2	—12	+ 3	+46	—56	40	0 27	+ 3	+ 7	0	+84	—59	
10	1.X 1957	20 14	52	2 20	+11	+36	— 3	—50	—44	52	22 40	— 5	—20	+ 4	+44	—53	50	0 30	+ 3	+18	0	+85	—59	
11	2.X 1957	20 21	48	1 47	+12	+29	+ 1	—66	—45	48	23 22	— 5	—11	— 1	+48	—61	45	0 34	+ 4	+ 9	0	+87	—58	
12	2.X 1957	20 56	52	1 43	+14	+29	+ 3	—68	—44	52	23 26	— 7	—11	— 3	+47	—62	50	0 34	+ 4	+ 9	0	+87	—58	
13	21.X 1957	20 37	45	2 54	+22	+47	+ 5	—53	—30	45	0 39	— 1	+ 9	— 5	+89	—62	41	1 44	+11	+28	0	—66	—48	
14	22.X 1957	17 31	40	3 03	+ 4	+44	—13	—37	—44	40	0 30	+18	+14	+13	+87	—44	35	1 48	+11	+29	0	—65	—47	
15	22.X 1957	18 37	37	3 09	+11	+48	— 7	—42	—37	37	0 27	+11	+10	+ 7	+85	—52	32	1 48	+11	+29	0	—65	—47	
16	22.X 1957	20 37	45	2 59	+22	+40	+ 4	—62	—30	45	0 42	0	+10	— 4	—74	—62	41	1 48	+11	+29	0	—65	—47	
17	23.X 1957	17 34	39	3 07	+ 5	+46	—12	—37	—43	39	0 33	+19	+15	+14	+88	—44	34	1 52	+12	+30	0	—64	—46	
18	23.X 1957	18 36	37	3 14	+12	+49	— 6	—42	—36	37	0 30	+12	+12	+ 8	+86	—51	32	1 52	+12	+30	0	—64	—46	
19	24.X 1957	18 ^h 35 ^m	36°	3 ^h 19 ^m	+11°	+50°	— 7°	—40°	—35°	36°	0 ^h 31 ^m	+11°	+12°	+ 7°	+86°	—51°	31°	1 ^h 56 ^m	+12°	+31°	0°	—63°	—46°	

With the aid of two direct vision prisms mounted on the spectrograph opening, the spectra of two contrasting regions, arranged symmetrically relative to the anthelion point at a distance of 20° from it, were obtained simultaneously with the spectrum of the sky at the anthelion point. In this case, by using this method in [1,2], the spectral intensities of the sky could be obtained in absolute units.

The results of the absolute spectro-photometrization of the airglow in the 4200-6500 Å region are given in this paper. The principal problem is the study of the continuous spectrum. However, we will also include some data on the emission in the blue part of the spectrum.

The observations were made in September and October of 1957 in the high-altitude station of the P. K. Shternberg State Astronomical Institute in Ala-Tau on the Zaliyskiy Mountains at an elevation of about 3000 m.

A description of the obtained materials is given in Table 1. In it are shown: the date of the observations, the moment of the middle of the exposure in Universal Time, and also the zenith distances and the equatorial, ecliptic, and galactic coordinates of the sky regions being studied. The ordinal number of the spectrum is given in the first column. The letter *g* signifies the anthelion region, and the letters *E* and *W* signify the eastern and western comparative regions.

GENERAL DESCRIPTION OF THE SPECTRA, AND RELATIVE EMISSION INTENSITY OF THE CONTINUOUS SPECTRUM

A reproduction of one of the spectrograms obtained is shown in Figure 1. The spectrum of the sky at the anthelion point is in the center. Above and below it are the spectra of the contrasting regions. The spectrum from the luminophore BS-6, which was used for standardization, is shown above. The principal emission lines of the night sky are clearly visible on the spectrogram (λ 5577, 5894, 6300); the emission bands in the blue part of the spectrum are also noticeable.

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A description of the emissions which were found and measured on our spectrograms is given in Table 2.¹ Most of the bands belong to an O_2 molecule. The bands which belong to Hertzberg's first system $^3\Sigma_u^+ - ^3\Sigma_g^-$ are marked with an asterisk. The wavelengths of the bands are given according to [3]. The most characteristic emissions on our spectrograms are near λ 4420 Å and λ 4890 Å. The first is formed from the merging of the intense (1.9) band with the neighboring (5.11) and (3.11) bands of Hertzberg's first system. The second

¹ The principal emission lines are not included in the table.

is probably formed from the merging of the (0.10) band of Hertzberg's first system with the (5.13) and (0.11) bands of Hertzberg's second system $^1\Sigma_u^- - ^3\Sigma_g^-$. The closely arranged emissions at λ 4530, 4570, and 4660, 4690 are not completely separated by our spectrograph. The emissions at λ 4330, 4470, 4940, and 5100 are probably caused entirely by the bands of Hertzberg's second system. The weak emissions near 5200 and 5260 obviously belong to hydroxyl (9.2) and (6.0) bands. The first of them is probably merged with the (0.11) band of Hertzberg's first system.

The total emission intensity in the 4200-5400 Å range, expressed in Rayleighs, is shown in Table 3.

The intensity of the emissions changes within very wide boundaries from 40 to 300 Rayleighs.

The ratio between the total emission intensity in the 4200-5400 Å range and the integral intensity of the continuous spectrum in this range varies from 0.04 to 0.30 and averages about 10%.

Fig. 1. Night-Sky Spectrum Obtained with the Aid of a Nebular Spectrograph.

The dependence between the integral intensity of the emission bands in the blue part of the spectrum and the intensity of the continuum in the 6000 Å range is shown in Figure 2. As we can see, such a dependence cannot be definitely developed in the whole (for a large number of spectra obtained at different times at various points in the sky). However, on certain nights, the intensities were marked by clearly defined measurements (for example, on October 2-3 and October 23-24), and a fairly close correlation is observed between the intensity of the continuum and Hertzberg's bands. An analogous phenomenon was noted in [4].

ABSOLUTE INTENSITY AND ENERGY DISTRIBUTION IN THE CONTINUOUS NIGHT-SKY SPECTRUM

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The average spectral intensity of the continuum in the 4200-6500 Å range at the high-altitude station GAISH at various moments of time are shown in Table 4. The intensity varies from 0.8 to 1.9 $R/\text{Å}$ and averages 1.5 $R/\text{Å}$, which is approximately 20-25% less than at Zvenigorod [5,6]. This small difference can be caused by errors in standardization, by the altitude effect, and also by the condition that, at Zvenigorod, the additional increase in the sky brightness as a result of the scattering of light in the lower layers of

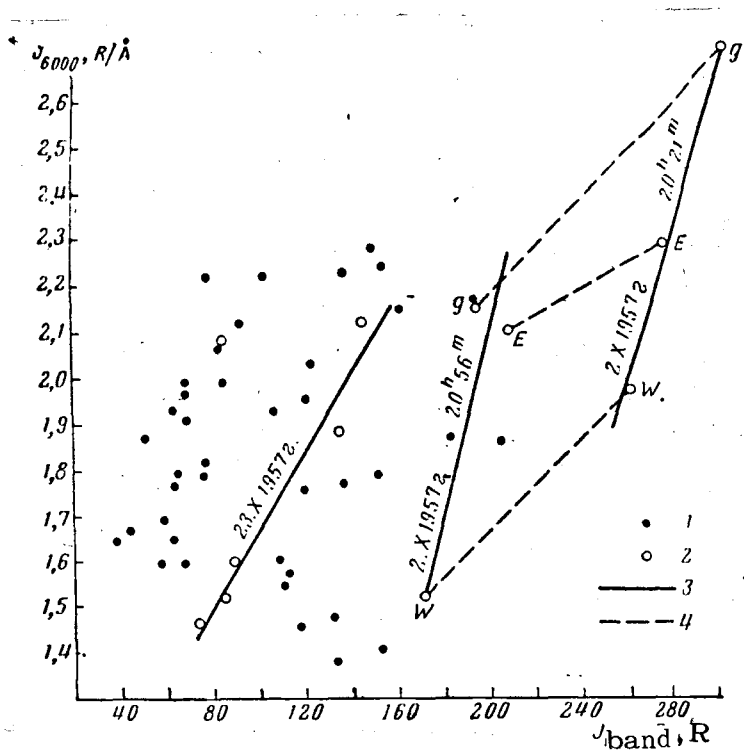


Fig. 2. Comparison of the Continuum Intensity at λ 6000 Å and the Intensity of Hertzberg's Band in the Blue Part of the Spectrum (1). The Values Pertaining to Those Nights When a Close Correlation Was Noted Between the Continuum Intensity and Hertzberg's Band (2). The Lines Corresponding to the Average Relationships for Points 2 (3). The Lines Connecting the Points Which Correspond to the *g*, *E*, and *W* Regions of the Sky (4). (The Moment of Exposure is Given in Universal Time.)

TABLE 2. EMISSION BANDS IN THE BLUE PART OF THE SPECTRUM

λ	No. of Spectra	Identification
4270	7	O ₂ 4266 (3,10); 4274 (4,10)*
4300	15	O ₂ 4308 (0,8)*
4330	19	O ₂ 4331 (5,11); 4332 (2,8); 4339 (0,9)
4425	28	O ₂ 4401 (3,10)* 4405 (5,11)* 4422 (1,9)*
4470	7	O ₂ 4465 (1,9); 4472 (3,8); 4482 (1,10)
4530	18	O ₂ 4531 (4,11)* 4544 (2,10)*; 4548 (6,12)*
4570	13	O ₂ 4579 (0,9)*
4660	39	O ₂ 4675 (3,11)*; 4692 (4,12)
4690		
4810	11	O ₂ 4806 (3,12); 4818 (4,12)*
4890	30	O ₂ 4878 (5,13); 4881 (0,10)* 4909 (0,11)
4940	14	O ₂ 4935 (2,12)
5000	15	O ₂ 4992 (4,13); 5016 (1,11)*
5100	5	O ₂ 5093 (3,10); 5122 (3,13)
5200	13	OH 5204 (9,2); O ₂ 5219 (0,11)*
5260	7	OH 5277 (6,0)

TABLE 3. TOTAL EMISSION INTENSITY IN THE
4200-5400 Å RANGE

No. of Spectrum	Total Intensity, R			No. of the Spectrum	Total Intensity, R		
	Region of the Sky				Region of the Sky		
	E	W	g		E	W	g
1	83	150	138	11	277	262	307
2	92	195	154	12	209	172	195
3	162	78	103	13	57	65	59
4	76	69	64	14	75	152	111
5	44	64	63	15	117	133	108
6	184	206	69	16	121	85	123
7	152	120	107	17	146	135	84
8	132	112	137	18	86	75	90
9	38	67	51	19	69	77	42
10	178	138	132				

TABLE 4. AVERAGE SPECTRAL INTENSITY OF THE CONTINUUM IN THE
4200-6500 Å RANGE

No. of the Spectrum	Average Spectral Intensity $R/\text{\AA}$			No. of the Spectrum	Average Spectral Intensity $R/\text{\AA}$		
	Region of the Sky				Region of the Sky		
	E	W	g		E	W	g
1	1,7	1,9	1,9	11	1,4	1,3	1,6
2	1,6	1,7	1,9	12	1,0	0,8	1,1
3	1,6	1,7	1,8	13	1,2	1,3	1,3
4	1,4	1,5	1,5	14	1,3	1,2	1,3
5	1,3	1,3	1,4	15	1,2	1,2	1,3
6	1,5	1,4	1,5	16	1,5	1,4	1,6
7	1,3	1,4	1,6	17	1,8	1,6	1,7
8	1,2	1,3	1,4	18	1,2	1,2	1,3
9	—	—	1,5	19	1,6	1,6	1,6
10	1,0	1,2	1,2				

the atmosphere should be more than under high-altitude conditions. The change in intensity from night to night at the high-altitude station is much less than at Zvenigorod, where, according to V. M. Morozov [5], the intensity of the continuum varies from 0.85 to 4.3 R/Å. Even greater changes were noted at Loparskaya. According to [7], the curve of the energy distribution reaches a peak near 5900 Å, whose intensity varies from 3 R/Å to 10 R/Å with an average value of 4.5 R/Å. According to our data, the intensity of the

continuum near 5900 does not exceed $2.5 R/\text{\AA}$, which is less than the minimum value recorded at Loparskaya. It is obvious that this is related to the altitude effects of the night-sky luminescence.

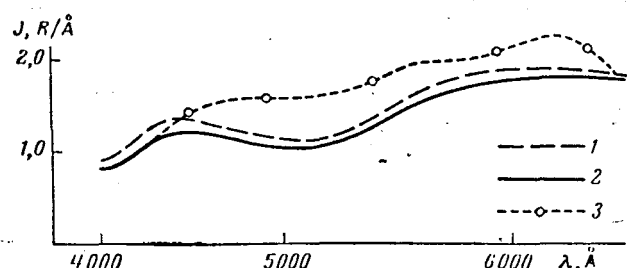


Fig. 3. Energy Distribution in the Continuous Night-Sky Spectrum. (1) Anthelion Range; (2) Contrasting Regions; (3) Composite Curve Obtained in [6].

The energy distribution observed in the continuous night-sky spectrum is shown in Figure 3 (without reduction for absorption and light scattering in the lower layers of the atmosphere).² Curve 1 gives the average energy distribution throughout all the spectra for the region of the sky in the anthelion range. Curve 2 gives the average energy distribution for the contrasting regions. Both curves are similar to each other. However, the absolute intensity in

the anthelion range is approximately 10% higher. This indicates that the counter glow is caused by an intensification of the continuous spectrum, and thus has a dust-like nature.

The composite curve of energy distribution obtained by N. N. Shefov [6] at Zvenigorod, on the basis of fairly extensive observational material, is shown in Figure 3 for the sake of comparison. These curves differ very little from one another in energy distribution. The presence of two peaks is characteristic (one near $\lambda 6000 \text{ \AA}$, and another near $\lambda 4600\text{--}4700 \text{ \AA}$). The energy distribution in the night-sky continuum bears no resemblance to that in the spectrum of the Sun. The presence of two peaks makes it dissimilar for the energy distribution in the spectrum of stars of other spectral classes, also. It is doubtless that the similar character of the curve is determined by the presence of a continuous emission. The idea that the nature of this emission in the blue part of the spectrum is different is not excluded; such a possibility was hinted at in [6].

A comparison of the continuum intensities in two spectral regions, $\lambda 6000 \text{ \AA}$ and $\lambda 4700 \text{ \AA}$, corresponding to the peaks in the energy distribution curve, is given in Figure 4. The figure substantiates Shefov's [8] correlation between the continuum intensities in these two spectral regions, and also a change in the character of the dependence at high intensities, as was indicated in [6].

² In the spectral range being studied, the average transparency coefficient for the high-altitude station of the P. K. Shternberg State Astronomical Institute varies from 0.78 at $\lambda 4200 \text{ \AA}$ to 0.93 at $\lambda 6500 \text{ \AA}$.

The latter circumstance indicates that there are changes in the continuum spectral composition. This problem is of great interest. A change in the continuum spectral content was found by Shefov [9] /32 and subsequently confirmed by other authors. However, this conclusion was disputed by Morozov [5,10]. An analysis of the energy distribution curves we obtained for each individual spectrum very definitely indicates real changes in the continuum spectral composition.

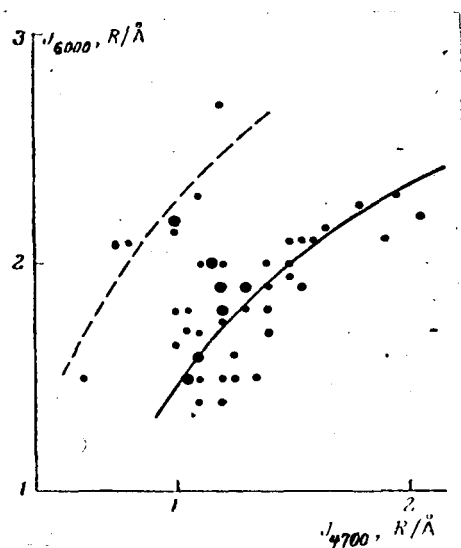


Fig. 4. Juxtaposition of the Continuum Intensities at Two Spectral Regions, λ 6000 and λ 4700 Å.

In connection with the discussion taking place [10-12] on a method for determining the intensities of the principal night-sky emission lines, λ 5577 Å and λ 5890 Å, a comparison of the continuum intensities at λ 5577, 5890, and 5280 Å is of special interest. The relative intensities of the continuum at λ 5577 and 5890 Å, expressed in Rayleighs and relative to the intensity at λ 5280 Å, is given in Table 5.

TABLE 5. RELATIVE CONTINUUM INTENSITIES

J_{5577}/J_{5280} and J_{5890}/J_{5280}

No. of the Spectrum	J_{5577}/J_{5280}			J_{5890}/J_{5280}		
	Region of the Sky					
	E	W	g	E	W	g
1	1,36	1,38	1,48	1,67	1,53	1,81
2	32	42	39	61	70	57
3	56	44	37	85	67	52
4	18	17	16	35	41	43
5	27	12	14	35	32	22
6	17	18	19	30	34	33
7	28	27	31	45	30	39
8	30	20	22	47	44	58
9	33	30	73	61	56	79
10	44	39	52	—	—	—
11	42	22	18	1,94	1,66	1,95
12	49	16	16	2,70	2,04	2,04
13	56	39	46	1,68	1,74	1,56
14	55	46	38	55	53	38
15	48	44	38	54	55	44
16	55	51	39	72	75	56
17	29	30	26	30	28	29
18	37	32	37	42	33	44
19	1,11	1,20	1,23	1,20	1,11	1,14

According to Morozov, the relative intensities J_{5577}/J_{5280} and J_{5890}/J_{5280} in the night-sky continuum vary slightly, and their average values are close to the corresponding values for the Sun. The data in Table 5 show that the relative continuum intensity J_{5577}/J_{5280} varies from 1.11 to 1.73 and averages 1.34, and the relative intensity J_{5890}/J_{5280} varies within even wider limits from 1.11 to 2.70 with an average value of 1.54. As we can see, the average values differ greatly from those for the Sun.

For the method of determining the intensity of the emission lines on the basis of photoelectric measurements, the principal question is: By measuring the continuum in the $\lambda 5300 \text{ \AA}$ range, and by using the constant ratio between the intensity of the continuum in this range and in the range of the emission lines, can we find the intensity of the continuum near the emission lines? The pres-

ence of variations in the continuum spectral composition leads to the necessity of calculating the continuous background by direct measurements near the emissions being studied, as V. I. Krasovsky [12] and N. N. Shefov [11] rightly maintain. Calculation of the continuum in the range of the lines by measuring its intensity near $\lambda 5300 \text{ \AA}$ results in errors which can reach 100% in certain cases. Therefore, it seems to us that the old method for determining the intensities is useful only for obtaining the average value for the emission intensity for a large number of observations and in that case when the correct value for the ratios J_{5577}/J_{5280} and J_{5890}/J_{5280} is taken. However, this method is completely useless for obtaining the variations in emission lines.

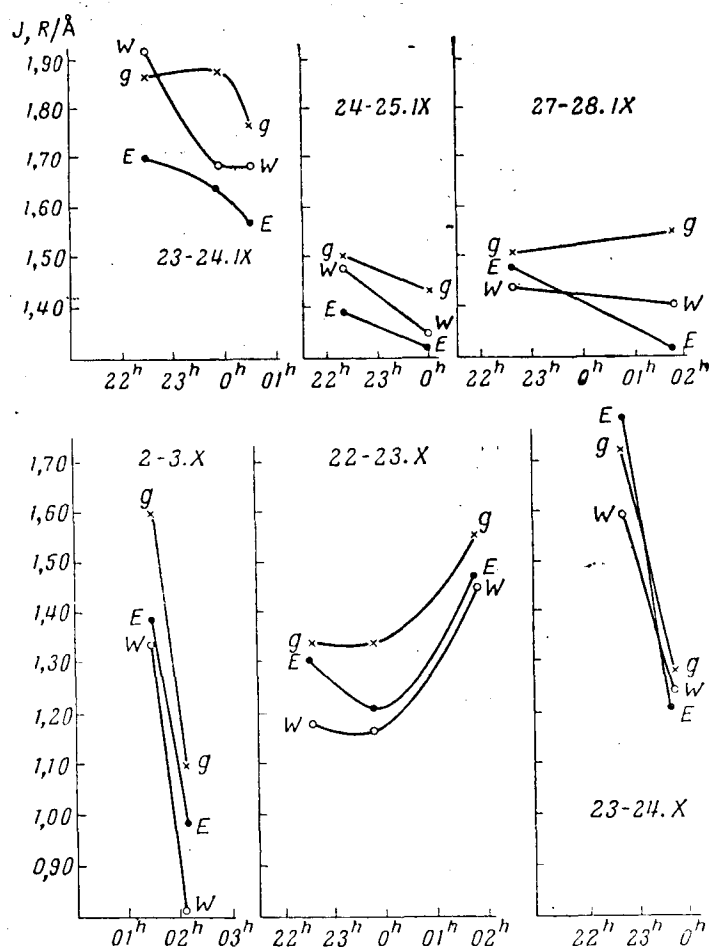


Fig. 5. Diurnal Variations of the Continuum Intensity. The Local Average Time is Plotted on the Abscissa.

The diurnal variations of the continuum intensity are shown in Figure 5. The reality of the changes is hardly doubtful. Unfortunately, the scanty mater-

ial does not provide for drawing definite conclusions as to the character of these variations. The greatest changes were noted on the night of October 2, 1957. The average continuum intensity that night at the western contrasting region fell in 30 minutes from 1.35 $R/\text{\AA}$ to 0.8 $R/\text{\AA}$. /34

According to [3], there are cases when the atmosphere in the continuous spectrum radiates nothing. If we consider that this took place on October 3 at about 02:00 local time, and, in correspondence with this assumption, if we take the upper margin for the intensity of the extra-terrestrial components in the continuum of the night sky as equal to 0.8 $R/\text{\AA}$, we find that the intensity of the atmospheric component for the ranges of the sky being studied averages 47%, and reaches 58% on some individual nights. Naturally, this gives us a lower margin for the intensity of the atmospheric component in the night-sky continuum.

REFERENCES

1. Pariyskiy, N. N. and L. M. Gindilis: Raspredeleniye energii v spektre protivosiyaniiya (Energy Distribution in the Counterglow Spectrum). Astron. Zhur., Vol. 36, pp. 1078-1090, 1959.
2. Pariyskiy, N. N. and L. M. Gindilis: Issledovaniye prirody protivosiyaniiya. Sbornik trudov MGU po Mezhdunaroknomu geofizicheskomu godu (astronomiya). (Studies on the Nature of Counterglow. Collection of Transactions of Moscow State University on the International Geophysical Year (Astronomy). Moscow State University, pp. 3-30, 1962.
3. Barbier, D.: Analyse du spectre du ciel nocturne (Analysis of the Night-Sky Spectrum). IAGA Bulletin No. 15b. Problèmes de la physique, de la haute atmosphère. Communications présentées à la réunion à Rome (September, 1954). Paris, 1956.
4. Yarin, V. I.: Nepreryvnyy spektr i polosy Gertsberga molekuly O_2 v izluchenii nochnogo neba. Sbornik: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Continuous Spectrum and the Hertzberg Bands of the O_2 Molecule in the Night-Sky Radiation. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 5, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 35-38, 1961.
5. Morozov, V. M.: Nekotoryye fotometricheskiye dannyye o kontinuuume v svechenii nochnogo neba (Some Photometrical Data on the Airglow Continuum). Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1887-1894, 1961.
6. Shefov, N. N.: Nepreryvnyy spektr v svechenii nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Continuous Airglow Spectrum. Collection:

- Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 5, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 39-41, 1961.
7. Taranova, O. G.: Nepreryvnyy fon v izluchenii nochnogo neba i polyarnykh siyaniy. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Continuous Background in Radiation of the Night Sky and Aurorae. Collection: Aurorae and Airglow), No. 8, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 21-23, 1962.
 8. Shefov, N. N.: Intensivnosti nekotorykh emissiy nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Intensities of Some Night-Sky Emissions. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 2-3, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 57-59, 1960.
 9. Shefov, N. N.: Intensivnosti nekotorykh emissiy sumerechnogo i nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Intensities of Some Emissions of the Twilight and Night Skies. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 1, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., pp. 57-59, 1960.
 10. Morozov, V. M.: O nepostoyanstve spektral'nogo sostava kontinuum v svechenii nochnogo neba (The Variability of the Continuum Spectral Composition in the Airglow). Ezvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 4, pp. 573-576, 1962.
 11. Shefov, N. N.: Zamechaniya po povodu nekotorykh vyvodov V. M. Morozova o kontinume v izluchenii nochnogo neba (Comments on Some of V. M. Morozov's Conclusions on the Airglow Continuum). Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1895-1897, 1961.
 12. Krasovskiy, V. I.: Pis'mo v redaktsiyu, Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1898-1900, 1961.

THE STATISTICAL TREATMENT OF PHOTOELECTRICAL MEASUREMENTS WITH FILTERS

O. G. Taranova

ABSTRACT: Elimination of the continuum intensity when emission observations are done with wide-band filters by way of making its measurements in the region with constant spectral distribution does not give correct intensities of discrete emissions. Statistical reduction of such data does not permit determining the true spectral distribution of the continuum and variations of its spectrum.

Several authors use the spectral continuum distribution according to the type of G2 star class to calculate the background in photoelectric measurements of the upper atmosphere emissions. But the spectral and photoelectrical measurements made with the aid of a scanning photometer and a photoelectric spectrometer indicate that there are variations of the spectral background distribution in time [1-13].

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In addition to these variations, the intensity and the spectral continuum distribution are found to have a spotty structure caused by the atmospheric luminescence component [13].

However, besides the direct methods for studying the properties of the continuous spectrum, an indirect statistical method applied by V. M. Morozov [14-16] was also used. During photoelectric observation of emissions with filters, the intensity of the background was measured in the region near λ 5300 Å, and the intensity of discrete Na emission was determined by subtracting the background intensity, which was calculated according to the G2 spectral distribution from the background intensity near λ 5300 Å, from the total intensity in the filter with λ 5890 Å. On the basis of a lack of correlation between the calculated Na intensity and the λ 5300 Å background, Morozov came to the conclusion that he selected the spectral continuum distribution according to G2 and its spectral continuity correctly.

* Numbers in the margin indicate pagination in the foreign text.

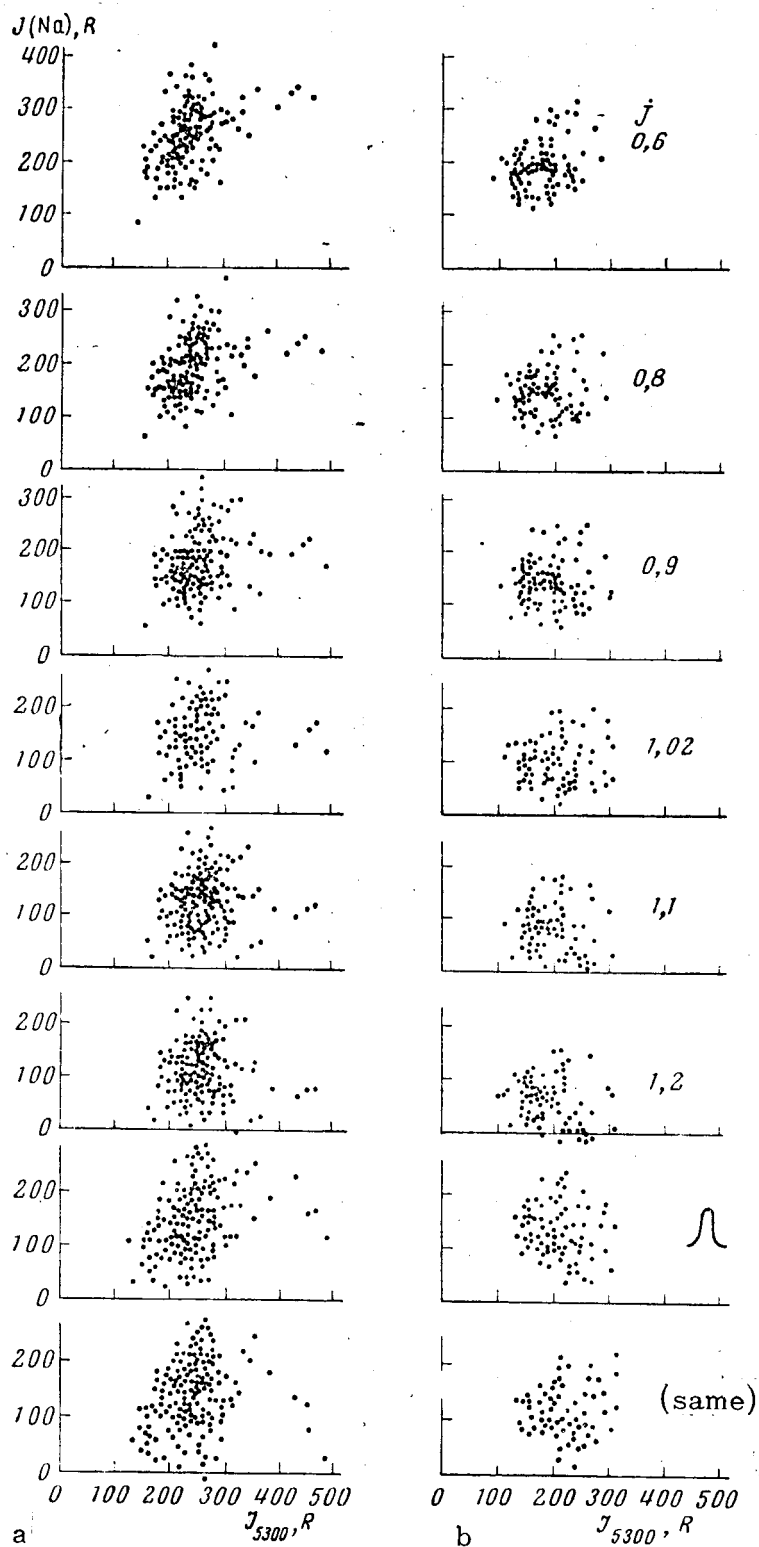


Fig. 1. Field of Correlation Between J_{5300} and J_{5890} for Various Values of j ($j = 0.6; 0.8; 0.9; 1.02; 1.1; 1.2$) and for a Random Selection of Values for j ($j = 0.8; 0.9; 1.02; 1.1; 1.2$), an Equally Probable Π , and a Normal Ω . (a) - Autumn, (b) - Spring.

Since the results of the statistical treatment by Morozov essentially contradict the data of direct measurements, a test was made for the sensitivity of the method of such statistical treatment for the type of spectral continuum distribution selected. For this purpose, Morozov elaborated on the data of the electrophotometrical measurements by using various types of continuous background spectra. The ratio of continuum intensities in the λ 5890 Å and λ 5300 Å regions was taken as equal to the following values: $j = 0.6; 0.8; 0.9; 1.02; 1.1; 1.2$, which corresponds to the star classes B0, A0, F0, G2, K0, K5. Comparisons of the background λ 5300 Å intensities and the calculated intensity ascribed to a discrete emission (in this case to Na and OH (8.2) emissions) are given in Figure 1. In this case only the observational data obtained at the time of a lack of aurorae at $K\text{-index} \leq 3$ were used for the analysis. The observation periods were divided, as Morozov did [14-16], into autumn and spring. As we can see from the figure, the character of distribution of the points varies very slightly with changes in the selected ratios for the continuum intensities j , from 0.6 to 1.2. Analogous results are also obtained for the coefficients of correlation r between the calculated intensities of the sodium emissions and the λ 5300 Å background for various given values of j (Table 1 and Fig. 2). The corresponding standard variations for a sodium emission are also shown there. As we can see from the figure, the values for the correlation coefficients for the autumn and spring periods are different for one and the same ratios of continuum intensities j . This corresponds to a redder average spectral distribution of the continuum for the spring period. This is also explained by the fact that the Milky Way fell within the photo-

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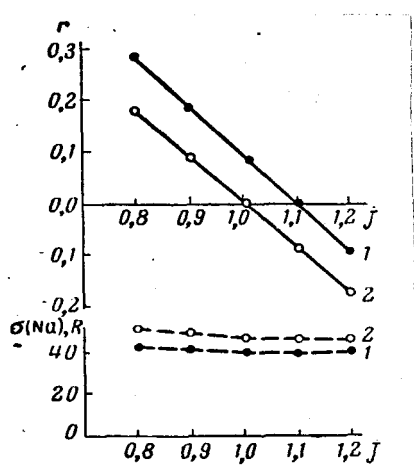


Fig. 2. Coefficients of Correlation r Between (Na, 5300) and the Values for $\sigma(\text{Na})$ Versus a Selected Value for j (5890, 5300) (1) Spring; (2) Autumn.

meter field of vision during the autumn-winter period. Thus the value for the stellar component in the total continuum increased greatly in comparison with the spring period, when the Milky Way did not lie within the field of vision. This fact already implies another - that even an average continuum spectral content varies during different periods.

In order to test the effect of the variations in the background spectral distribution on the results of comparison of these two emissions, we examined the observational data by using a random selection of various values for the intensity ratios of the continuum near λ 5890 and λ 5300 Å. For this purpose, we selected two variants from the selection for possible values of the ratio j . In the first variant, the values $j = 0.8; 0.9; 1.02; 1.1; \text{ and } 1.2$ were

considered equally probable (rectangular distribution of possibilities). In the second variant, we had a normal (Gaussian) distribution with a maximum for $j = 1.02$ (G2). The selection was made in the first case with the aid of a sudden disturbance by a rotating pentagon with a marking for the sides, and in the second case by a four-fold projection of a coin. The results of the comparison are shown in Figure 1, and the coefficients of correlation are given in Table 1. The shape of the graphs practically does not differ from any others. The coefficients of correlation are also close to zero.

TABLE 1. COEFFICIENTS OF CORRELATION BETWEEN THE CALCULATED INTENSITY FOR A SODIUM EMISSION AND THE CONTINUUM NEAR $\lambda_{5300}\text{\AA}$ VERSUS A GIVEN SPECTRAL DISTRIBUTION FOR THE CONTINUUM j .

	n	j	r	r^2	m_r	$\frac{m_r}{ r }$	$\bar{J}(\text{Na}), R$	$\sigma(\text{Na}), R$	$\sigma/\bar{J}, \%$
Autumn	160	0,8	0,18	0,032	0,072	0,40	147	53	36
		0,9	0,10	0,010	0,075	0,75		51	35
		1,02	0,0013	0,000	0,078	60		50	34
		1,1	-0,088	0,008	0,078	0,90		49	33
		1,2	-0,16	0,025	0,078	0,50		49	33
		$\square$	0,09	0,008	0,078	0,87		51	35
		Ω	0,001	0,000	0,078	78		48	33
Spring	88	0,8	0,28	0,078	0,11	0,40	95	43	45
		0,9	0,19	0,036	0,11	0,58		42	44
		1,02	0,084	0,007	0,11	1,3		42	44
		1,1	-0,014	0,000	0,11	7,9		42	44
		1,2	-0,098	0,009	0,11	1,1		42	44
		$\square$	0,02	0,000	0,11	5,5		42	44
		Ω	0,12	0,014	0,11	0,9		41	43

According to [17-20], we can calculate the average error m_r for the calculated coefficients of correlation r to be $m_r = (1-r^2)/\sqrt{n}$, where n is the number of observations. The value of m_r provides for calculating the possible margins for the correlation coefficients and for determining in this way the validity of the values obtained. The values of r , r^2 , and m_r for various cases, based on observations by Morozov, are given in Table 1. /38

According to [19], the correlation coefficient will be equal to the one observed with a probability equal to 0.99 in the case when

$$\frac{m_r}{|r|} < 0,3.$$

From Table 1 it follows that, on the average, $m_r = \pm 0.1$ for various cases examined. In order to increase the reliability for the value of r , we must greatly increase the number of observations, in comparison with the ones we have.

If we are limited by the obtained values for m_r , then, as follows from Figure 2, the ambiguity in the value for r in this case

corresponds to the limits for changes in j from 0.8 to 1.2. However, the error in j by 10-15%, as was shown earlier in [8], with a continuum intensity of ~ 2 Rayleighs/Å and with a width of the filters of about 100 Å, will correspond to the error in the intensity of the background near λ 5890 Å of about 20-30 Rayleighs on the average, which is about 50% of the intensity of an Na emission in the flow penetrating the filter.

All that we have said above shows that the statistical method used by Morozov for indicating the type and variability of the background spectral distribution is not sensitive to the value for the intensity ratio of the continuum near λ 5300 Å and λ 5890 Å, and cannot give conclusions on the character of the variations in the spectral continuum distribution. The inaccurate calculation for the ratio j , naturally, will result in negative values for the intensity of a sodium emission. The selection of small values for j , at which negative values are not obtained, has a very arbitrary character (see Fig. 1). As a result of the ambiguity of the properties of the correlation coefficient for a relatively small number of observations, and also by the method used for indicating the type of continuum spectrum, only that spectral distribution of the background which was assumed earlier is confirmed. However, as we can see from the data obtained, we can obtain any previously assigned value for j (naturally, within certain limits) by this method.

By a series of direct observations of emissions at two different filters, we can divide all the data into the correlating and non-correlating parts. According to [20], the coefficient of correlation between two combinations of values J_0 and J_1 will be the following:

$$r_{01} = \frac{\overline{J_1 J_0} - \overline{J_0} \overline{J_1}}{\sqrt{(\overline{J_1^2} - \overline{J_1}^2)(\overline{J_0^2} - \overline{J_0}^2)}}. \quad (1)$$

During photoelectric observations, the background is usually calculated according to the following relationship:

$$J_0 = J_2 - j J_1, \quad (2)$$

where J_2 is the total intensity observed for discrete emission of the background, J_1 is the intensity observed for the background in another spectral range, j is the given relationship between the background J_1 and the background in the spectral range of measurements for J_2 , and J_0 is the calculated intensity for discrete emission. Considering (2), we can determine j_0 , for which $r_{01} = 0$, i.e., the coefficient of regression, from (1):

$$j_0 = \frac{\overline{J_1 J_2} - \overline{J_1} \overline{J_2}}{\overline{J_1^2} - \overline{J_1}^2}.$$

Thus the calculated value of j_0 allows us to isolate the average part which does not correlate with J_1 of the total intensity J_2 , in the given case for J_0 .

Thus, for the λ 5700 Å emission (after excluding the filtration of the λ 5577 Å line), we found that the coefficient of correlation was equal to zero when $j_0 = 1.12$ for the autumn and $j_0 = 1.06$ for the spring. These values coincide with an accuracy up to 0.03 with the average intensity ratios for λ 5700 Å and λ 5300 Å, after calculating the effect of the λ 5577 Å emission. However, the values obtained for j_0 are only the average effective values for the given combination of values, since there were substantial divergences from the average values ($\sim 15\text{--}20\%$) during the given periods for measurements. Therefore, the average values for j_0 cannot be used for any judgments on the residual intensity of the emission in this range, since this necessarily results in negative values for the intensity of such an emission.

Figure 3, (a) and (b), shows comparisons of intensities for the continuum with λ 5300 Å and the calculated λ 5700 Å emission, after excluding the G2 background and the effect of λ 5577 Å and λ 5890 Å, which the filter penetrates. The points which correspond to the observations during the autumn-winter periods from 1957 to 1959 are plotted in Figure 3 (a). We can see from the graph that the λ 5700 Å intensity for a certain part of the observations is negative. The coefficient of correlation corresponding to this graph is $r = 0.7$.

The points corresponding to observations only in 1958, on the basis of which Morozov drew his conclusion on the existence of an emission near 5700 Å, are plotted in Figure 3 (b). In this case, $r = 0.05$. In the first case we can speak about a dependence between the remaining λ 5700 Å intensities and the λ 5300 Å continuum, but in the second case we cannot. The obtained results depend greatly on the amount of data used. This clearly indicates that the calculated emission near λ 5700 Å is part of the background which remains after subtracting the part of the continuum which was taken as corresponding to the G2 type of distribution.

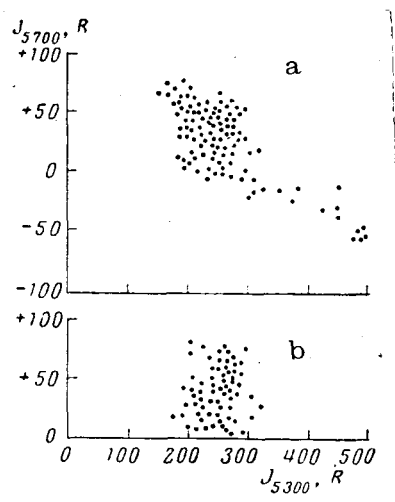


Fig. 3. Comparison of Intensities Between the Calculated λ 5700 Å Emission and the λ 5300 Å Background. (a) Autumn Periods from 1957-1959; (b) Autumn Period in 1958.

We must emphasize the fact that the average values obtained for the spectral continuum distribution in the airglow, and the corresponding coefficients of correlations, have in essence more of a probability than a real qualitative value. As was shown in [17], these characteristics do not by themselves produce possibilities for a certain "prediction" of

the possible results for future observations of a random value. This "prediction" can be included in a consideration of the probability that the amount for a certain value is within certain limits.

For the observations in filters with λ 5300 Å and λ 5577 Å, also, we can determine the corresponding values of j_0 . In this case, $j_0 = 1.24$ for the autumn, and $j_0 = 1.52$ for the spring. In order to test the results obtained, we examined the data for the observations conducted in Ashkhabad by Yu. L. Truttse. These observations provide for a direct calculation of the background at λ 5577 Å, since a combination of two filters was used for the λ 5577 Å emission. We examined the observations made for two nights. For one night, there was little spottiness in the λ 5577 Å line, and for the second night, there was great spottiness in the λ 5577 Å line. The results of the examination are given in Table 2. The second column gives the ratio between the average total intensity observed in the λ 5577 Å filter and the average intensity observed in the λ 5300 Å filter. These ratios clearly coincide for Zvenigorod and Ashkhabad. The third column shows the coefficient of correlation between the directly observed values for the intensities in the λ 5300 Å and λ 5577 Å filters. The values for these correlation coefficients decrease greatly in the autumn (according to Morozov's data) as well as during the night with great spottiness in the λ 5577 Å line (according to Truttse's data). The values for j_0 and j , calculated according to the observations in Ashkhabad, are given in the next two columns. We can see from Table 2 that, the more the coefficient of correlation between the directly observed values decreases, the more the values for j_0 differ from the average ratios of background intensities. Therefore, although the results of the statistical treatment (according to Morozov's and Truttse's data) coincide, the values obtained are not the ratio of background intensities, since direct measurements of the intensity ratios give values for j_0 which differ from j . The values obtained for j_0 can serve only as a certain lowermost margin for the values of j .

TABLE 2. COMPARISON OF RESULTS FOR STATISTICAL TREATMENT OF PHOTO-ELECTRIC OBSERVATIONS

Observation Site and Author 1		$\frac{j_{5577} + B_1}{j_{5300}}$	r	j_0	j_{av}	No. of Measurements
Zvenigord	Autumn	2,6	0,5	1,24	—	160
(V.M.Morozov)	Spring	2,3	0,8	1,52	—	88
Ashkhabad	I	2,4	0,6	1,24	1,45	96
(Yu.L.Truttse)	II	2,6	0,25	0,38	1,67	96

I - Night with little spottiness in the λ 5577 Å line;
 II - Night with great spottiness in the λ 5577 Å line.

All this, of course, does not mean that the statistical method for analysis is not applicable in all cases. We must only select correctly the range for its application and pay close attention to the conclusions obtained, to the evaluation of the criteria for sensitivity in the method applied and also to the physical nature of the dependences derived.

It is interesting to examine from this point of view the effect of the character of the point distribution for the field of correlation on the statistically derived relationships.

For this purpose, we examined two cases of the effect of "overshooting" the points from the basic distribution on the correlation coefficients (Fig. 4).

First Case. The correlation coefficient was equal to zero in the original distribution. Then points were added outside this non-correlating distribution at various distances from it.

Second Case. The original distribution was a combination of points arranged inside an extended ellipse, with a correlation coefficient equal to 0.7. Points with varying densities were added around the ellipse. The correlation coefficients for these cases

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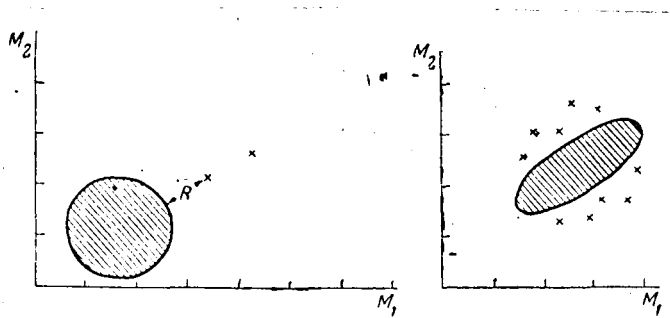


Fig. 4. Field of Correlation for Two Types of Overshooting Points in Relation to the Total Combination of Data.

incident values during the observations, even if their number is small, can either strengthen the dependence to a great degree (first case) or eliminate this dependence (second case). The correlation coefficients for Morozov's data on the λ 5890 Å and λ 5300 Å emissions for $j = 1.02$, when there were supplementary observations at the time of aurorae and with the K -index > 3 , are given as an example in Table 4. The

TABLE 3. EFFECT OF ADDING POINTS WHICH DIFFER FROM THE GENERAL COMBINATION OF POINTS IN THE FIELD OF CORRELATION ON THE CORRELATION COEFFICIENT

Character of Field of Correlation	Variant I			Variant II	
	<i>n</i>	<i>r</i>		<i>n</i>	<i>r</i>
Circle	300	0,000	Ellipse	300	0,705
Circle+Origin of Coord.	303	0,124		310	0,57
Circle+1R	303	0,056		330	0,42
Circle+2R	303	0,136		340	0,36
Circle+3R	303	0,372		360	0,32

dependence of the conclusions obtained on the number of measurements was already mentioned for the emission near λ 5700 Å. This shows again that, in a statistical treatment of a relatively small amount of data, we must analyze with care the material obtained.

TABLE 4. CORRELATION COEFFICIENTS VERSUS THE AMOUNT OF DATA USED FROM OBSERVATIONS

Combination of Data	Autumn		Spring	
	n	r	n	r
$K_{ind} \leq 3$	160	0,0013	88	0,084
$K_{ind} \leq 3 + K_{ind} > 3$	210	0,050	157	0,033
$K_{ind} \leq 3 + \text{Aurora}$	215	0,017	124	0,20
$K_{ind} \leq 3 + K_{ind} > 3 + \text{Aurora}$	265	0,064	193	0,22

REFERENCES

1. Struve, O., C. T. Elvey and F. E. Roach: Reflection Nebulae, /42 Astrophys. J., Vol. 84, No. 2, pp. 219-228, 1936.
2. Karyagina, Z. V. and L. N. Tulenkova: Spektrofotometricheskiye issledovaniya nepreryvnogo i emissionnogo spektra nochnogo neba v vizual'noy oblasti (Spectral Photometrical Studies on the Continuous and Emission Spectrum of the Night Sky in the Visible Range), Izvest. Astrofiz. Instit. Akad. Nauk Kazanskiy S.S.R., Vol. 9, pp. 86-95, 1959.
3. Fishkova, L. M. and G. V. Markova: Nekotoryye rezul'taty elektrometricheskikh nablyudeniy emisiy OI, Na, OH i nepreryvnogo fona v svechenii nochnogo neba (Some Results of Electrometrical Observations on the Emissions of OI, Na, OH, and the Continuous Background in Airglow), Byull. Abastum. Astrofiz. Observ., No. 24, pp. 161-173, 1959.
4. Fishkova, L. M. and G. V. Markova: Nekotoryye rezul'taty elektrofotometricheskikh i spektrograficheskikh nablyudeniy svecheniya nochnogo neba v Abastumani. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Some Results of Electrophotometrical and Spectrographical Observations of the Airglow in Abastumani. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 2-3, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 49-56, 1960.
5. Shefov, N. N.: Intensivnosti nekotorykh emissiy sumerechnogo i nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Intensities of Some Twilight- and Night-Sky Emissions. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 1, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 25-29, 1959.

6. Shefov, N. N.: Intensivnosti nekotorykh emissiy nochnogo neba. Sb.: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Intensities of Some Night-Sky Emissions. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 2-3, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 57-59, 1960.
7. Shefov, N. N.: Nepreryvnyy spektr v svechenii nochnogo neba. Sb.: Spektarl'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (The Continuous Spectrum in the Airglow. Collection: Spectral, Electrophotometrical, and Radar Studies on Aurorae and Airglow), No. 5, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 39-42, 1961.
8. Shefov, N. N.: Zamechaniya po povodu nekotorykh vyvodov V. M. Morozova o kontinue v izluchenii nochnogo neba (Comments on V. M. Morozov's Conclusions on the Airglow Continuum), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1895-1897, 1961.
10. Taranova, O. G.: Nepreryvnyy fon v izluchenii nochnogo neba i polyarnykh siyaniy. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Continuous Background in the Airglow and the Aurora. Collection: Aurorae and Airglow), No. 8, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 5-7, 1963.
11. Truttse, Yu. L.: Spektral'noye raspredeleniye zvezdnoy i atmosferno y sostavlyayushchikh kontinuumma v svechenii nochnogo neba. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Spectral Distribution of the Stellar and Atmospheric Continuum Components in the Airglow. Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 5-7, 1963.
12. Truttse, Yu. L.: Izmereniye fona pri fotoelektricheskikh nablyudeniyakh emisii [OI] 5577 Å. Sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (Measurements of the Background in Photoelectrical Observations of the [OI] 5577 Å Emission. Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG", Izdat. Akad. Nauk S.S.S.R., pp. 8-12, 1963.
13. Truttse, Yu. L.: Variatsii spektral'nogo raspredeleniya kontinuumma svecheniya nochnogo neba (The Spectral Variations of the Airglow Continuum), This Collection, p.1.
14. Morozov, V. M.: Nekotoryye fotometricheskiye dannyye o kontinue v svechenii nochnogo neba (Some Photometrical Data on the Continuum in Airglow), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 12, pp. 1887-1894, 1961.
15. Morozov, V. M.: O nepostoyanstve spektral'nogo sostava kontinuumma v svechenii nochnogo neba (The Variability of the Continuum Spectral Content in Airglow), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 4, pp. 573-576, 1962.
16. Morozov, V. M.: Nekotoryye osobennosti emissii [OI] λ 5577 Å i kontinuumma v svechenii nochnogo neba (Some Features of the [OI] λ 5577 Å and the Airglow Continuum Emissions), Izvest. Akad. Nauk S.S.S.R., seriya geofiz., No. 10, pp. 1446-1449, 1962.

17. Shchigolev, B. M.: Matematicheskaya obrabotka nablyudeni
(Mathematical Treatment of Observations), Fizmatgiz, 1960.
18. Mitropol'skiy, A. K.: Tekhnika statisticheskikh vychisleniy
(The Techniques of Statistical Calculations), Fizmatgiz, 1961.
19. Velikanov, M. A.: Oshibki izmereniya i empiricheskiye zavis-
imosti (Measurement Errors and Empirical Dependences),
Gidrometizdat, Leningrad, 1962.
20. Worsing, A. and J. Heffner: Metody obrabotki eksperimental'-
nykh dannyykh (Methods for Developing Experimental Data),
Inostrannaya Literatura, 1953.

CORRELATIONS BETWEEN EMISSIONS IN THE UPPER ATMOSPHERE

N. N. Shefov

ABSTRACT: Types of correlation between the upper atmosphere emissions and their physical content are considered.

The investigation of radiations in the upper atmosphere long ago revealed the existence of highly diverse types of variations in emission intensity, and in the temperatures corresponding to them (Doppler, vibrational, rotational, etc.). The study of the changes in space and time which occur in these parameters provides an opportunity for gaining an idea of the geophysical properties of the emissions in the upper atmosphere which in turn provide information regarding the mechanisms governing the production of these emissions. Inasmuch as many atoms and molecules radiate at altitudes which are more or less close to one another, it is then natural to assume the existence of an interaction between the various emissions. All of this is certainly of value in explaining the question of the processes taking place in the observed atmospheric glow. However, regardless of the theoretical clarity of such hypotheses, the problem of the correlations between the various emissions as well as their relationships to other phenomena of helio- and geo-activity is considerably complicated. In the atmosphere itself, the variation of emissions is due simultaneously to a variety of causes including processes of excitation as well as atmospheric dynamics. The uneven structure of the emissions observed in recent years must be taken into account carefully in determining e.g., short-term diurnal variations. In addition, in a number of cases the variations which are related to the mechanism by which radiations are produced can conceal other processes whose variations have a different nature. Mention has already been made [1, 2] of a possible co-variation of emissions owing to changes in pressure and temperature. All of this will have a marked influence on various emissions. Thus, as a result of the general interaction of processes in the upper atmosphere, there will be a tremendous number of links between the observed phenomena. Therefore, in order that we can make any statement regarding the actual mechanisms by which the glow occurs, it is necessary to select only those correlations which have a physical or practical significance.

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An experiment in carrying out a comparison of the properties of various emissions, both among themselves and with other phenomena, has still failed to yield any significant results about the nature of these emissions. However, it is necessary to mention that in studying the interactions between two phenomena, cases of close correlation were studied, which correspond to the rough proportionality of the parameters under investigation. Under the conditions of the real atmosphere, however, even the inter-related emissions will have a dispersion which is of relatively average proportionality. This dispersion depends on the number of independently varying parameters, which determine two components of the phenomenon.

All of the numerous processes which can lead to the formation of excited atoms and molecules which then irradiate light quanta, can be divided into two categories (the two-component and three-component reactions). The general form of a two component reaction is the following: /44



The asterisk indicates an excited particle. If one of the colliding particles is a fast particle, i.e., possesses a higher energy relative to the thermal energy of the medium in question, then the reaction can take the form:



In addition to this simple excitation, there can also be ionization and dissociation. However this does not change the substance of the process.

The general form of the three-component reaction can be represented as follows:



where the particles U , V and M can be atoms and molecules. The number of particles formed depends on the type of colliding particles.

Each process of excitation in which it is possible for radiation to occur produces a quantum of light



The intensity of the emission in quanta is

$$J(h\nu) = A[XY^*]H,$$

where A is the probability of spontaneous transition, $[XY^*]$ is the concentration of XY^* particles, and H is the scale of the altitude of the radiant layer of the atmosphere.

The concentration of excited particles produced in two-component and three-component reactions are equal respectively to

$$[XY^*] = [XZ][Y] \alpha_2 e^{-\frac{E}{kT}} \tau_{XY^*} \quad (5)$$

$$[UV^*] = [U][V][M] \alpha_3 \tau_{UV^*} \quad (6)$$

Here the values in brackets indicate the concentrations of the respective particles, α_2 and α_3 are the coefficients of the reaction rates ($\alpha \sim \sqrt{T}$), E is the activation energy, T is the temperature of the medium, τ is the average lifetime of excited products of the reaction. Since under the conditions in the upper atmosphere (and particularly in night-sky radiation) the deactivation of excited particles takes place primarily as a result of second-order collisions, then

$$\tau = \frac{1}{\Sigma A + \beta [M]},$$

where β is the coefficient of the reaction rate of deactivation.

Thus, the intensities of the emissions produced in the reaction described above will be determined by the following equations:

$$J_2 = [XZ][Y] \frac{\alpha_2 A H}{\Sigma A + \beta [M]} e^{-\frac{E}{kT}}, \quad (7)$$

$$J_3 = [U][V][M] \frac{\alpha_3 A H}{\Sigma A + \beta [M]}. \quad (8)$$

In the general case, each emission can arise as a result of a great many different processes which act simultaneously. However, under the actual conditions, the most effective is some single process which can be viewed as the basic one. It may be that the simultaneous occurrence of two or more processes considerably complicates the nature of the variations in the intensity of the emission.

Therefore let us for the sake of simplicity consider the correlation between the intensities of the emissions determined by the two-component and three-component reactions.

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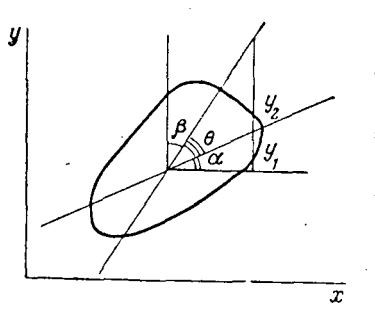
Then the ratio of the intensities is:

$$\frac{J_{2a}}{J_{2b}} = \frac{[XZ_a][Y_a]}{[XZ_b][Y_b]} \cdot \frac{\alpha_{2a} \cdot A_a \cdot H_a}{\alpha_{2b} \cdot A_b \cdot H_b} \cdot \frac{\Sigma A_b + \beta_b [M_b]}{\Sigma A_a + \beta_a [M_a]} \cdot e^{-\left(\frac{E_a}{kT_a} - \frac{E_b}{kT_b}\right)}, \quad (9)$$

$$\frac{J_{2a}}{J_{3c}} = \frac{[XZ_a][Y_a]}{[U_c][V_c][M_c]} \cdot \frac{\alpha_{2a} \cdot A_a \cdot H_a}{\alpha_{3c} \cdot A_c \cdot H_c} \cdot \frac{\Sigma A_c + \beta_c [M_c]}{\Sigma A_a + \beta_a [M_a]} \cdot e^{-\frac{E_a}{kT_a}}, \quad (10)$$

$$\frac{J_{3c}}{J_{3d}} = \frac{[U_c][V_c][M_c]}{[U_d][V_d][M_d]} \cdot \frac{\alpha_{3c} \cdot A_c \cdot H_c}{\alpha_{3d} \cdot A_d \cdot H_d} \cdot \frac{\Sigma A_d + \beta_d [M_d]}{\Sigma A_c + \beta_c [M_c]}, \quad (11)$$

From these formulas it is clear that the variations in the ratios of the relative intensities of the emissions produced in a given region of altitude are determined by the concentrations of the reacting components. When both emissions are formed in exactly the same reaction, both final products being excited, it is only then that we can consider the strict proportionality of these emissions. Such a result will also be obtained in the case when the reaction has a somewhat ramified structure. However, in actuality such cases are clearly encountered only rarely. If one of the components of the reaction is a general one and the other is different, then there



Field of Correlation
of Compared Emissions.

will be a certain dispersion of the values of the quantities in question relative to some average relationship between emission intensities. As a result, the field of correlation between these emissions will show a collection of points within a certain sector. The aperture angle of such a sector depends on the variation of the relative content of independent components of the reactions being compared. If all the components of these reactions have independent variations, then the points in the correlation field can fill the entire area.

In actuality, the components of many chemical reactions are not primary particles but give rise to other processes as a result. Therefore the concentrations of some atoms and molecules contained in the atmosphere can be related to a certain degree by intermediate reactions. Simultaneous action of several processes leading to the production of a given emission will increase the scatter of the points in the correlation field for the emissions being compared.

Thus, if the points in the correlation field are distributed within a certain sector, this is in no way an indication that there is a lack of relationship between the emissions. For such a coincidence of points, as shown in the figure, it is possible to determine in the usual manner both the coefficient of correlation r and the direct regressions. The coefficient of regression for Y as a function of $X_p = \operatorname{tg} \alpha$. The angle θ between the direct regressions is determined from the equation:

$$\operatorname{tg} \theta = \frac{r(1-r^2)}{r^2 + p^2}. \quad (12)$$

Inasmuch as not one of these direct regressions in this case constitutes an average dependence between the measured values, it is possible to find the angle of slope ϕ of the straight line determined by the condition that the total of the squares of it is minimal up to four measured points [3]. For this line

$$\operatorname{tg} 2\varphi = \frac{2\rho r^2}{r^2 - \rho^2} \cdot \quad (13)$$

The value of the coefficient of correlation in this particular case determines the range of variation of the value Y for a given X . As we see from the figure,

$$\frac{Y_2}{Y_1} = \frac{1}{r^2} \cdot \quad (14)$$

Thus, the presence of this kind of correlation between two emissions must be attributed to the existence of two components: reactions which lead to the appearance of the observed emission. In addition, these types of correlations must be observed more frequently than is the case of close proportionality.

In addition, the location of this kind of relationship is clearly preferable, since (in addition to the property mentioned) they make it possible to determine the range of relative variations of other components of the reactions and thus to provide some understanding of the dynamics of the processes in the upper atmosphere. For excluding random correlations, it is necessary to have a corresponding interpretation for the occurrence of each kind of emission being compared.

However, in a number of cases the emissions in the upper atmosphere exhibit a highly nonuniform relationship from both the statistical and physical points of view. The reason for this to a large degree is that for comparing them we used data from observations which were not carried out especially for explaining the concrete properties of emissions and failed to take into account several peculiarities of the occurrence of the phenomena being compared. This shortcoming was partly to blame in the spectrographic observations which averaged the observed emission over a long period of time and thus masked the random structure of the radiation. As a result, in comparing the emissions measured in this way, data were frequently compared which were based on long periods of time at different seasons of the year. This made it possible to explain the average relationships, but again concealed the fine structure of the variations; however, the average relationships themselves can have seasonal variations and can depend on solar and geoactivity cycles.

Another contradiction was the electrophotometric measurements of emission by means of wide-band filters aimed in a given direction (the zenith, e.g.). Thanks to the short time occupied by each measurement period, such data can be used profitably to reveal the irregular structure of the glow. This obviously leads to the chaotic diurnal variations of various emissions which have been observed. In addition, the diverse nature of the variations in stellar and atmospheric components of the continuum produces nonuniformity of the relationships obtained between the various emissions.

The average statistical relationships formed on the basis of such observations can provide only a qualitative picture of the phenomena.

That which has been stated above does not mean that such data are unsuitable for studying the properties of the upper atmosphere. The measurements which were carried out made it possible to obtain a preliminary idea regarding the observed properties of emission. However, the quality of the information which can be obtained in this method of observation is limited. Such a peculiarity in a number of previous experiments was caused on the one hand by the fact that practically nothing was known about the emissions being studied and on the other hand the fact that there were technical difficulties in studying weak emissions. Nevertheless, the conclusions which have been drawn from the results obtained make it possible to devise some experiments which will have some concrete value.

A more accurate idea regarding the nature of the variations in the emission is given by observations conducted by means of scanning photometers and spectrometers which make it possible to study the irregular structure of the glow. This means that averaging of data for time and space and random variations in measurement are all avoided. /47

Depending on the theoretical mechanisms for production of the emissions being compared, there may arise a need to determine the properties of these emissions at certain specified points in the sky and even in different directions [4]. All of this indicates that it is inadequate to carry out a correlation of the emissions whose measurements have not been carried out especially for that particular purpose. It is incomparably more profitable and informative to seek correlations in order to check concrete theories by means of special observations.

REFERENCES

1. Krasovskiy, V. I.: Nature of the Intensity Variations of the Terrestrial Atmospheric Emission, in: *Les Molécules dan les Astres (The Molecules in the Stars)*, Cointe-Selessin, Belgium, pp. 58-67, 1957.
2. Krasovskiy, V. I.: *Priroda Izmeneniy Intensivnosti Emissiy Zemnoy Atmosfery (Nature of the Intensity Variation of the Terrestrial Atmospheric Emission)*, Izdatel'stvo Akad. Nauk SSSR, *Seriya geofizicheskaya*, No. 5, pp. 664-669, 1957.
3. Menzel, D. (ed.): *Osnovnyye Formuly Fiziki, Pod Red D. Menzela (Basic Formulas of Physics)*. Moscow, Foreign Language Publishing House, 1957, p. 78.
4. Truttse, Yu. L.: *Prostranstvennyye Variatsii Intensivnosti Kislorodnykh Liniy (Spatial Variations of Intensity of Oxygen Lines)*. This collection, p. 61.

UPPER-ATMOSPHERIC EMISSION AND NOCTILUCENT CLOUDS

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ABSTRACT: According to observations at Zvenigorod during the period of 9-14 July 1962, when noctilucent clouds appeared, the minima of intensity and of rotational temperature of the OH and O₂ emissions occurred on the night following the appearance of noctilucent clouds.

Noctilucent clouds are usually observed in summer during the period of twilight illumination of the atmosphere. However, noctilucent clouds have occasionally been observed in winter as well [1-3]. They occur at altitudes of approximately 80 km, which corresponds to a region of a temperature minimum. The structure of the clouds shows a particularly pronounced undulatory and irregular appearance [4, 5]. According to rocket measurements [6-8], various emissions arise in this region of the atmosphere, primarily bands of hydroxyl OH and bands of the atmospheric system of molecular oxygen O₂. /48*

Experiments carried out in recent years have indicated that the rotational temperature of the OH and O₂ bands has a pronounced minimum in summer and a maximum in winter [9-16]. This result shows good agreement with the results of rocket measurements [17]. According to spectrographic observations at Zvenigorod [12, 15, 16] in summer (from the beginning of May to the end of August), the rotational temperature of OH bands with low rotational levels ($v' \leq 5$) are equal to about 170° K on the average and show a scatter of values from 150-200° K. For OH bands with high variational levels ($v' \geq 6$), the rotational temperature is higher on the average. This clearly corresponds to the radiation of the different OH bands at different levels. The rotational temperature of the (0.1) O₂ $\lambda 8645$ Å band is equal on the average to the rotational temperature of OH bands with the level $v' \leq 5$ and is about 10% less on the average than for the OH bands with $v' \geq 6$. If the rotational temperature reflects the temperature of the medium, then the observation of the hydroxyl and oxygen emission during the period of occurrence of noctilucent clouds makes it possible to determine the properties of the atmosphere at heights of about 80 km.

At the present time there are two theories regarding the nature of noctilucent clouds: the condensation theory and the dust theory. According to the first, noctilucent clouds are made up of ice crystals, while the second holds that they are made of dust

* Numbers in the margin indicate pagination in the foreign text.

particles.

The calculations of I. A. Khvostikov [18-20] and Z. A. Bronshten [21] indicate that the appearance of noctilucent clouds according to the condensation theory requires a temperature in this region of the atmosphere of 150-160° K.

In the summer of 1962, spectrographic observations of the emissions in the upper atmosphere were carried out; noctilucent clouds were observed on the night of 11-12 July. Spectrographs were aimed northward at an angle of 30° to the horizon. Figure 1 shows the variations in the intensity of the OH (6.2) $\lambda 8400$ Å band and the (0.1) O₂ $\lambda 8645$ Å band and the rotational temperature of OH (6.2). As we can see from this figure, the minimum rotational temperature and emission intensity were observed not on the night when the noctilucent clouds occurred but on the next night.

Unfortunately, nothing can be said regarding the regularity of such a phenomenon, since this is still the only case of such simultaneous observations. However, the change in the rotational temperature and the intensity of OH and O₂ may reflect in reality a change in the altitude of the glow caused by these emissions [22, 23].

An interesting result was obtained by comparing the intensities and the rotational temperatures of the OH and O₂ emissions (Fig. 2). The solid line in Figure 2 shows the average relationship between $\lg J(\text{OH})$ and $1/T(\text{OH})$, obtained at Yakutsk [10, 14]. Although a similar relationship for the OH bands with $v' = 6$ is practically lacking on the basis of the data collected at Zvenigorod, it is possible that it is sometimes observed for individual periods. The existence of a relationship between $\lg J(\text{O}_2)$ and $1/T(\text{OH})$ has already been pointed out in [12, 15, 16].

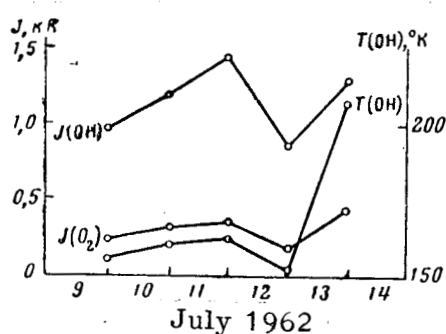


Fig. 1. Variations in Intensity and Rotational Temperature of OH and O₂ Emissions. Noctilucent Clouds Were Observed on the Night of 11-12 July 1962.

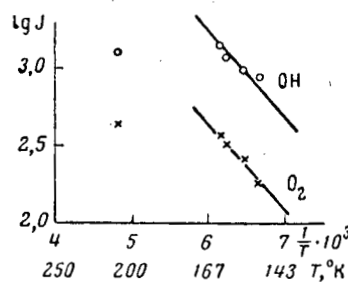


Fig. 2. Comparison of Intensity and Rotational Temperature of OH and O₂ Emissions.

Comparison of the data from observations of noctilucent clouds on the basis of spectrographic measurements of emission has still not yielded any definite results, since there was insufficient data available. The information which was available is listed in the table.

It is certain that in order to clarify the relationship between these two phenomena it is necessary to carry out further simultaneous observations. Determination of the nature of the particles composing noctilucent clouds has already been made with the aid of direct rocket studies [28].

The author thanks N. I. Grishin for compiling the data on the observations of noctilucent clouds during recent years in the Soviet Union.

DATA ON SIMULTANEOUS OBSERVATIONS OF NOCTILUCENT CLOUDS AND THE OH BANDS

Date	Noctilucent Clouds			OH Emission			
	Location	Coord.	Author	Location	Coord.	$T, ^\circ K$	Author
27-28.I 1960	Czech..	45°20'	[1]	Abastu	42°43'	240	[24]
8-9.VI 1960	Moscow	56 37	[25]	mani	56 37	175	
9-10.VI 1960	Moscow		[25]	Zvenigorod	56 37	155	
26-27.VI 1960	Gorky	56 44	[25,26]	Zvenigorod	56 37	162	
27-28.VI 1960	Gorky	56 44	[25,26]	Zvenigorod	56 37	166	
	Riga	57 24	[27]				

REFERENCES

1. Kviz, Z. and A. Mrkos: Visual and Photoelectric Observations of Noctilucent Clouds. Bull. Astron. Inst. Czechoslovakia, Vol. 11, No. 6, p. 253-254, 1960.
2. Teyfel', V. G.: Serebristyye oblaka nad Sredney Aziyey (Noctilucent Clouds above Central Asia). Astron. Tsirk., No. 218, p. 25-26, 1961.
3. Villmann, I. I.: Nablyudeniye serebristyykh oblakov zimoy (Observation of Noctilucent Clouds in Winter). Astron. Tsirk., No. 230, p. 29-30, 1962.
4. Grishin, N. I.: Volnovyye dvizheniya i meteorologicheskiye usloviya poyavleniya serebristyykh oblakov (Undulatory Motions and Meteorological Conditions of Occurrence of Noctilucent Clouds), in: Nekotoryye Problemy Meteorologii (Problems of Meteorology), No. 1 in series "Rezultaty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 117-119, 1960.
5. Witt, G.: Height, Structure and Displacement of Noctilucent Clouds. Tellus, Vol. 14, No. 1, p. 1-18, 1962.

6. Packer, D. M.: Altitudes of the Night Airglow Radiations. Ann. Geophys., Vol. 17, No. 1, p. 67-75, 1961.
7. Tarasova, T. M.: Pryamyye izmereniya svetimosti nochnogo neba (Direct Measurements of the Night Sky Airglow). Astron. Tsirk., No. 228, p. 31-32, 1961.
8. Tarasova, T. M.: Pryamyye izmereniya svetimosti nochnogo neba v spektral'noy oblasti $\lambda 8640 \text{ \AA}$ (Direct Measurements of the Night Sky Airglow in the Spectral Range of $\lambda 8640 \text{ \AA}$), in: Iskusstvennyye sputniki Zemli (Artificial Earth Satellites). Izdatel'stvo Akad. Nauk USSR, No. 13, p. 107-109, 1962.
9. Wallace, L.: Seasonal Variation and Interpretation of the OH Rotational Temperature of the Airglow. J. Atm. Terr. Phys., Vol. 20, No. 2-3, p. 85-93, 1961.
10. Krassovskiy, V. M., N. N. Shefov, and V. I. Yarin: On the OH Airglow. J. Atm. Terr. Phys., Vol. 21, No. 1, p. 46-51, 1961.
11. Fishkova, L. M. and G. V. Markova: Emissiya OH po nablyudeniyam v Abastumani (OH Emission According to Observations at Abastumani), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric, and Radar Studies of the Aurora and Night-Sky Airglow), No. 6 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 17-20, 1961.
12. Berg, M. A. and N. N. Shefov: Emission of the Hydroxyl Bands and of the $(0.1) \lambda 8645 \text{ \AA}$ Atmospheric Band of Oxygen in the Nightglow. Planet. Space Sci., Vol. 9, No. 4, p. 167-171, 1962.
13. Fishkova, L. M.: Sezonnyye i godichnyye variatsii intensivnosti svecheniya nochnogo neba v Abastumani (Seasonal and Annual Variations in the Intensity of the Night-Sky Airglow at Abastumani), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Aurora and Night-Sky Airglow), No. 9 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 5-9, 1962.
14. Yarin, V. I.: Variatsii naselennostey kolebatel'nykh yrovney molekul gidroksila (Variations in the Population of the Rotational Levels of Hydroxyl Molecules), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Aurora and Night-Sky Airglow), No. 9 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 10-18, 1962.
15. Berg, M. A. and N. N. Shefov: Emissiya OH i atmosfer'naya polosа $\lambda 8645$ molekuly O_2 (OH Emission and the Atmospheric Band of $\lambda 8645$ of O_2 Molecules), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Aurora and Night Sky Airglow), No. 9 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk. USSR, p. 46-52, 1962.
16. Berg, M. A. and N. N. Shefov: Gidroksil'naya emissiya s razlichnym kolebatel'nyy vozvuzhdeniyem (Hydroxyl Emission with Diverse Rotational Excitation), in: Polyarnyye

- siyaniya i svecheniye nochnogo neba (Aurora and Night-Sky Airglow), No. 10 in series "Rezul'taty MGG" Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 19-23, 1963.
17. Nordberg, W. and W. G. Stroud: Results of IGY Rocket-Grenade Experiments to Measure Temperatures and Winds above the Island of Guam. J. Geophys. Res., Vol. 66, No. 2, p. 655-664, 1961.
 18. Khvostikov, I. A.: Teplovoy rezhim atmosfery v zone serebristyykh oblakov (Thermal Regime of the Atmosphere in a Zone of Noctilucent Clouds), in: Trudy Soveshchaniya po Serebristym Oblakam (Proceedings of the Conference on Noctilucent Clouds), Tartu, 1958. Izdatel'stvo Akad. Nauk ESSR, p. 85-90, 1959.
 19. Khvostikov, I. A.: O prirode serebristyykh oblakov (The Nature of Noctilucent Clouds), in "Nekotoryye problemy meteorologii (Problems of Meteorology), No. 1 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 112-114, 1960.
 20. Khvostikov, I. A.: Serebristyye oblaka i stroyeniye atmosfery (Noctilucent Clouds and the Structure of the Atmosphere), in: Trudy Soveshchaniya po Serebristym Oblakam (Proceedings of the Conference on Noctilucent Clouds), Tallinn, 1961. Izdatel'stvo Akad. Nauk ESSR, No. 3, p. 7-13, 1962.
 21. Bronshten, V. A.: O prirode serebristyykh oblakov (The Nature of Noctilucent Clouds), in: Nekotoryye problemy meteorologii (Problems of Meteorology), No. 1 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 120-123, 1960.
 22. Krassovskiy, V. I.: Hydroxyl Emission in the Upper Atmosphere. Planet. Space Sci., Vol. 10, p. 7-17, 1963.
 23. Krasovskiy, V. I.: Gidroksil'naya emissiya verkhney atmosfery (Hydroxyl Emission in the Upper Atmosphere), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Aurora and Night-Sky Airglow), No. 10 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk USSR, p. 24-34, 1963.
 24. Fishkova, L. M.: Vrashchatel'naya temperatura gidroksil'nogo izlucheniya verkhney atmosfery (Rotational Temperature of the Hydroxyl Radiation of the Upper Atmosphere). Byull. Abastum. astrofiz. obs., No. 29, p. 55-76, 1962.
 25. Kurilova, Yu. V.: Aerosinopticheskiye issledovaniya usloviy obrazovaniya serebristyykh oblakov (Aerosynoptic Investigations of the Conditions of Formation of Noctilucent Clouds), in: Trudy Soveshchaniya po Serebristym Oblakam (Proceedings of the Conference on Noctilucent Clouds), III, Tallinn. Izdatel'stvo Akad. Nauk ESSR, p. 131-149, 1962.
 26. Demidovich, E. G. and S. G. Kulagin: Nablyudeniya serebristyykh oblakov Gor'kovskim otdeleniyem VAGO v 1960 godu (Observations of Noctilucent Clouds by the Gorky Branch of the All-Union Astronomical and Geodetic So-

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- ciety in 1960), in: Trudy Soveshchaniya po Serebristym Oblakam (Proceedings of the Conference on Noctilucent Clouds), III, Tallinn. Izdatel'stvo Akad. Nauk ESSR, p. 157-163, 1962.
27. Dirikis, M. A.: Rabota po serebristym oblakam v Rizhskom otdelenii VAGO v 1960 godu (Work on Noctilucent Clouds by the Riga Branch of the All-Union Astronomical and Geodetic Society in 1960), in: Trudy Soveshchaniya po Serebristym Oblakam (Proceedings of the Conference on Noctilucent Clouds), III, Tallinn. Izdatel'stvo Akad. Nauk ESSR, p. 164-168, 1962.
28. Witt, G., C. L. Hemenway, and R. K. Soberman: Collection and Analysis of Particles from the Mesopause. Proc. IV COSPAR Symposium, Warsaw, 1963.

SPATIAL VARIATIONS OF INTENSITY OF OXYGEN LINES

Yu. L. Truttse

ABSTRACT: The pattern structure of the green and red lines of atomic oxygen and of the continuum differ greatly in different regions of the spectrum. Spectral spot structure of the continuum is observed for the regions $\lambda 5300 \text{ \AA}$ and $\lambda 5577 \text{ \AA}$. Green and red patterns of the same linear dimensions and situated on the same geomagnetic line of force are found in different parts of the sky because these spots are located at different heights.

INTRODUCTION

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Regular electrophotometric observations of the green ($\lambda 5577 \text{ \AA}$) and red ($\lambda \lambda 6300, 6364 \text{ \AA}$) lines were carried out from September 1961 to August 1962 at the Astrophotometric Laboratory of the Institute of Physics and Technology of the Academy of Sciences of the Turkmenian SSR. The observations were carried out by means of a scanning photometer, which was described in [1, 2] with technical data of observations. Since an indirect purpose for the observations was the determination of the spatial variations of the intensity of the emission lines, considerable stress was laid on the accuracy of the measurement of the integral continuum of the night sky, the intensity and spectral distribution of which shows considerable variation as a function of the equatorial and horizontal coordinates of the observed region of the sky, as well as being a function of the time of observation [3-14].

In this connection, the intensity of the green line [OI] $\lambda 5577 \text{ \AA}$ was determined by means of two filters, centered on the portion of the spectrum at $\lambda 5577 \text{ \AA}$ [15], similar to the method used by Barbier for observing the red oxygen line [16]. This method permits a rapid and accurate determination (when the filters are used correctly) of the intensity of the emission line, without providing any information regarding the intensity and spectral distribution of the integral continuum. The filters which are used must satisfy the condition

$$\frac{k_1}{\Delta\lambda_1} - \frac{k_2}{\Delta\lambda_2} \neq 0, \quad (1)$$

* Numbers in the margin indicate pagination in the original text.

where $\Delta\lambda_1$, $\Delta\lambda_2$ are the equivalent widths of the range of total transmission of the first and second filters [15]; k_1 , k_2 are the transmission coefficients for λ_{5577} Å of the first and second filters. The intensity of the J_{5577} line is determined in this case by the expression

$$J_{5577} = \frac{\Delta\lambda_1 J_2 - \Delta\lambda_2 J_1}{\Delta\lambda_1 k_2 - \Delta\lambda_2 k_1}, \quad (2)$$

where J_1 , J_2 are the intensities in Rayleighs, recorded in the first and second filters. If we use the direct readings of the photometer without converting them first to Rayleighs, as is more conventional in practice, the solid angles of the two channels will be equal so that expression (2) will assume the form:

$$J_{5577} = \frac{i_{5577}^* 4\pi \Delta\lambda_1 \Delta\lambda_2}{n_1^* n_2^* (k_1 \Delta\lambda_2 - k_2 \Delta\lambda_1)} (n_1 n_2^* - n_2 n_1^*), \quad (3)$$

where i_{5577}^* is the energy of the continuous spectrum of the calibration star, taken over 1 Å in the portion λ_{5577} Å; n_1^* , n_2^* are the readings of the photometer from the calibration star in the first and second filters, respectively; n_1 , n_2 are the readings of the photometer from the sky in the first and second filters.

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To convert the results obtained, we used parallel observations of the green line on the spectroelectrophotometer. The agreement of the results was improved. It did appear advantageous to us to use the spectroelectrophotometer directly for observation of the

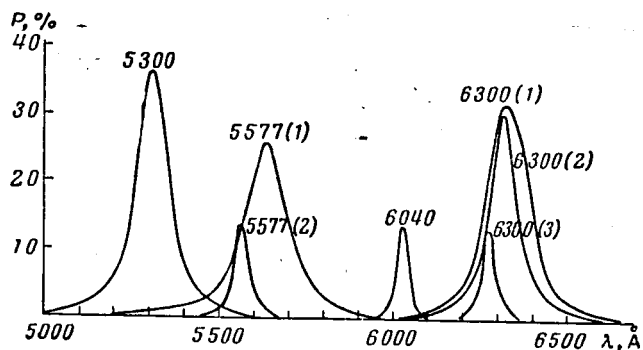


Fig. 1. Transmission Curves of the Filters.

spatial variations of the green line, in view of the much slower scanning rate relative to the scanning electrophotometer. It should be pointed out that the speed of the latter (the entire sky was scanned in about 16 min) appeared to us to be inadequate for clarifying all of the problems related to the spatial variations of the emission lines of the night-sky airglow.

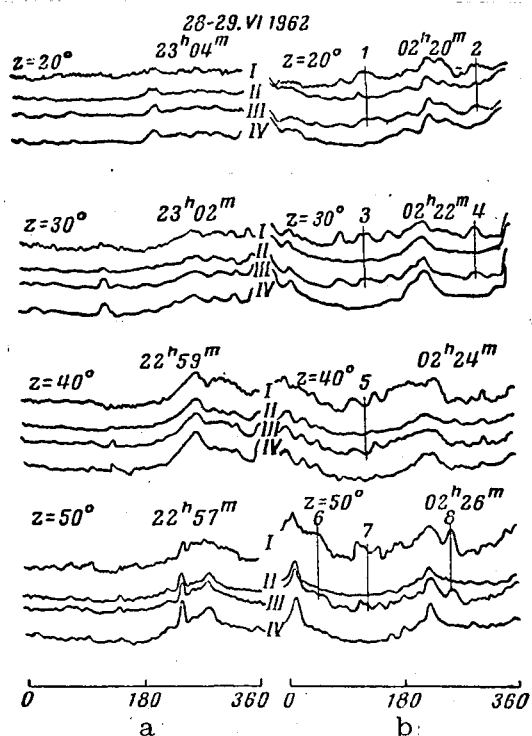
In observing the red oxygen lines 6300 Å, 6364 Å, the integral continuum for these wavelengths was obtained by extrapolating data regarding the continuum obtained from observations of portions of the spectrum at 5300 Å and 6030 Å. The method of two filters was used once again, as described in [16]. The intensity values obtained by different methods, as well as their pattern, very often show considerable variation. We did not judge it pos-

sible to check the correctness of the results obtained on the spectroelectrophotometer. Hence, further analyses will deal only with the features of the red line, which occur independently as a method of analyzing the observed material. The transmission curves of the interference filters used are shown in Figure 1.

SPATIAL VARIATIONS OF INTENSITY OF THE GREEN LINE

Many authors [17-22] have mentioned the existence of spatial variations of the intensity of the airglow at 5577 Å. Their observation does not pose any particular difficulties. Figure 2 shows recordings of the intensities measured at different zenith distances using filters centered on the spectral ranges 5300 and 6300 Å, and in two filters centered on the 5577 Å frequency. The measurements were made on the night of 28-29 June 1962. In Figure 2,a we see the recordings for the case of uniform radiation on 5577 Å while Figure 2,b is for the case of existence of noticeable irregularities, i.e., "spots". In this same region of the spectrum, we can clearly see the sharp difference in the pattern of the intensities, as recorded with the 5577, 5300, and 6300 Å filters. The intensity in Spot No. 1 is 20% higher (in Spot No. 8, 50% higher) than the intensity of the radiation in adjacent portions. Hence, the sensitivity of the apparatus appears to be completely adequate for solving the problems posed.

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The angular resolution (about 5°) also appears to be adequate. The intensity distribution over the sky can change very rapidly, and the periods of time in which photometry of individual regions of the sky (about 16 min) appear to be very long indeed in several cases. Figure 3a and b shows recordings of intensities measured with the 5577 Å filter along a single

Fig. 2. Recordings of Intensity in Different Filters With Uniform (a) and Spotty (b) Radiation at 5577 Å. Recordings for different Almucantars are Shown. I. Filter 5577(1); II. 6300; III. 5577(2); IV. 5300. The Numbers 1-8 Stand for Nonuniformity of Radiation.

almucantar with an interval of 16 (a) and 4 (b) minutes. As we can see, the distribution of intensities along the almucantars changes significantly. For comparison, the same recordings of intensity were made with the 5300 Å filter along the same almucantars for the same periods of time. There was practically no noticeable shift in the intensities in this filter. Hence, the example given indicates that for investigation of rapid spatial variations of intensity in the 5577 Å range, which undoubtedly occur, we will require instruments which can carry out photometry on the entire sky in a much shorter period of time.

It should also be mentioned that the presence of spatial inhomogeneities of intensity of radiation in the 5577 Å range is not an exceptional phenomenon. Brighter regions of radiation, "spots", are observed 60% of the total time of observation. Nights on which the spottiness was not detected at all are rare and do not amount to more than 15% of the total number of observation nights. However, the probability of occurrence of spots during the night depends on the time of observation. Figure 4 shows the frequency of spot occurrence as a function of observation time. The time in the figure is given in standard time. The spots occur most frequently immediately after midnight. At the beginning and end of night, not a single case of spottiness was recorded.

The increase in the radiation intensity at 5577 Å cannot always be explained merely by the increase in the intensity of the green line [OI] 5577 Å. In a number of cases, along with the increase in the emission line, there was also an increase in the continuum of the night sky. However, a corresponding intensification of the continuum at 5300 Å was not detected. Hence, the increase in the continuum took place only in a limited wavelength interval. The short wave limit of the amplification (as the electrospectrophotometric observations which were carried out at the same time revealed) occurs in the 5450-5500 Å region. The long wave limit, if such a thing exists, cannot be established due to the sharp drop-off in the sensitivity of the spectroelectrophotometer with increasing wavelength. /55

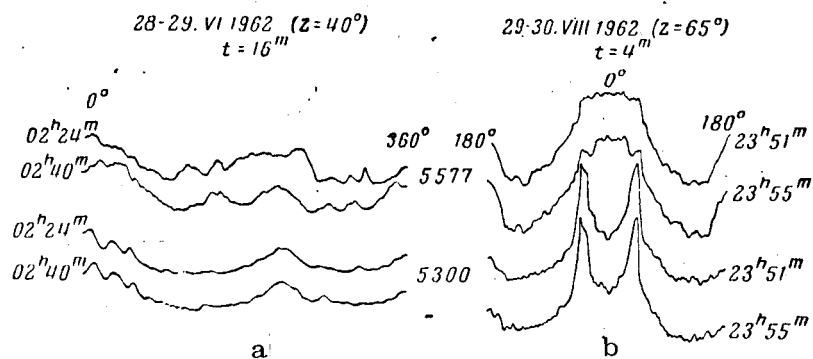


Fig. 3. Recordings of Intensities at 5300 and 5577 Å, Obtained Successively After 16 Min (a) and 4 Min (b).

The value of the integral continuum, necessary at $1 \text{ \AA}$ for the $\lambda 5577 \text{ \AA}$, i_{5577}^k range, is determined from the expression

$$i_{5577}^k = \frac{i^* 4\pi}{\omega n_1^* n_2^* (k_1 \Delta \lambda_2 - k_2 \Delta \lambda_1)} (n_2 n_1^* k_1 \Delta \lambda_2 - n_1 n_2^* k_2 \Delta \lambda_1), \quad (4)$$

where the symbols are the same as those in Equation (3). Comparison of these equations permits us to find a rapid means of distinguishing between the inhomogeneities in which the increase in the continuum takes place simultaneously with the increase in the intensity of the green line. In fact,

$$J_{5577} \sim n_2 \frac{n_1^*}{n_2^*} - n_1, \quad (5)$$

and

$$i_{5577}^k \sim n_1 - n_2 \frac{n_1^* k_1 \Delta \lambda_2}{n_2^* k_2 \Delta \lambda_1}, \quad (6)$$

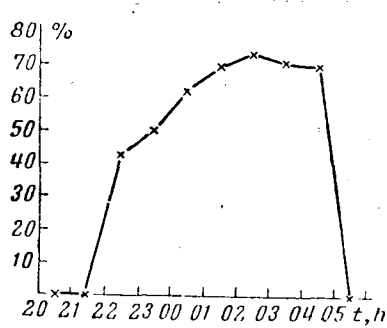


Fig. 4. Frequency of Spot Occurrence as a Function of the Observation Time During the Night.

i.e., if the increase in intensity in the spot is caused only by an increase in the intensity of the green line, the increase in residues in one of the filters Δn_1 will be greater than in the other Δn_2 (due to the different ratios $k_1/\Delta \lambda_1$ and $k_2/\Delta \lambda_2$). However, if there is a contribution of the continuum, then the difference between Δn_1 and Δn_2 will decrease while with particularly sharp increase in intensity of the continuum the sign may even change. From Equations (5) and (6) it is easy

to obtain the boundary conditions for determining whether an increase in the line intensity occurs in the spot or whether the continuum increases, or again whether the two increase simultaneously. If the intensity of the green line in the spot is greater, then the following equation must hold:

$$\frac{n_1^*}{n_2^*} - 1 > \frac{\Delta n_1 - \Delta n_2}{\Delta n_2}, \quad (7)$$

if the intensity of the continuum has increased, then

$$1 - \frac{n_1^* k_1 \Delta \lambda_2}{n_2^* k_2 \Delta \lambda_1} < \frac{\Delta n_2 - \Delta n_1}{\Delta n_2}, \quad (8)$$

where Δn_1 , Δn_2 are the increase in the photometer readings in the spot, while the remaining symbols are the same as those in Equation (3).

If both ratios are observed simultaneously, then there is an increase of both the continuum and the line in the spot. In Figure 5a, we have presented a recording of such a spot which was recorded on the night of 29-30 May 1962. The increase in the contin-

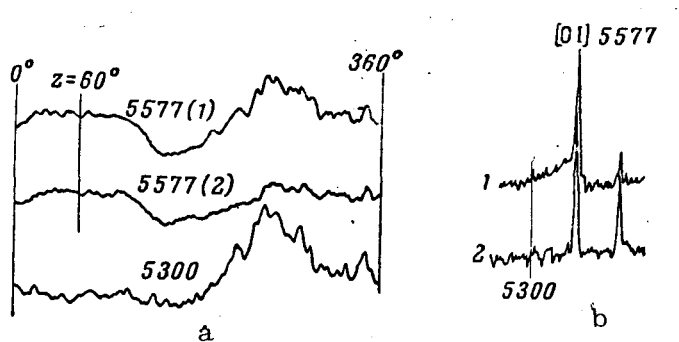


Fig. 5. Example of Spectral Variation of Background between the 5300 and 5577 Å segments. Recordings of Scanning Electrophotometer with Three Channels (Ashkhabad, 29-30 May 1962, 2345) (a); Vertical Line shows Center of Spot. Recording of Spectrum (Zvenigorod) (b).

1-2-3 March 1959, 2012-0230; 2-8-9 Nov. 1958, 1900-0420.

uum in the spots (according to our observations) can reach a factor of two. In Figure 5b, we have reproduced a spectrogram (1) with a similar increase of the continuum in the 5577 Å region, as obtained by N. N. Shefov at Zvenigorod. A spectrogram (2) with an ordinary continuum level is also shown for comparison. It is possible to assume that the increase in the integral continuum in the spot takes place as a result of its atmospheric component, since the occurrence of such spots is not related in any way to specific areas of the sky.

Regions of increased intensity of radiation at 5577 Å are rather mobile formations [17, 20, 23]. In Figure 6a, b, and c, there is a series of diagrams of the intensity distribution of the green line for the sky, as obtained during a period of two hours on the nights of 28-29 and 29-30 June 1962. The time when the diagrams were made was selected so that the stellar component of the continuum was approximately uniform for each pair of diagrams. From the diagrams we can clearly see the rapid changes in both the shape and intensity and position of the spots. The spot sizes can vary from values on the order of 20-30 km up to more than 700 km. The diagrams show the concentrations of fine spots at the zenith. This fact is explained by the drop in the linear resolution of the electrophotometer with increase in zenith distance z . Other authors have not mentioned the existence of fine inhomogeneities [27].

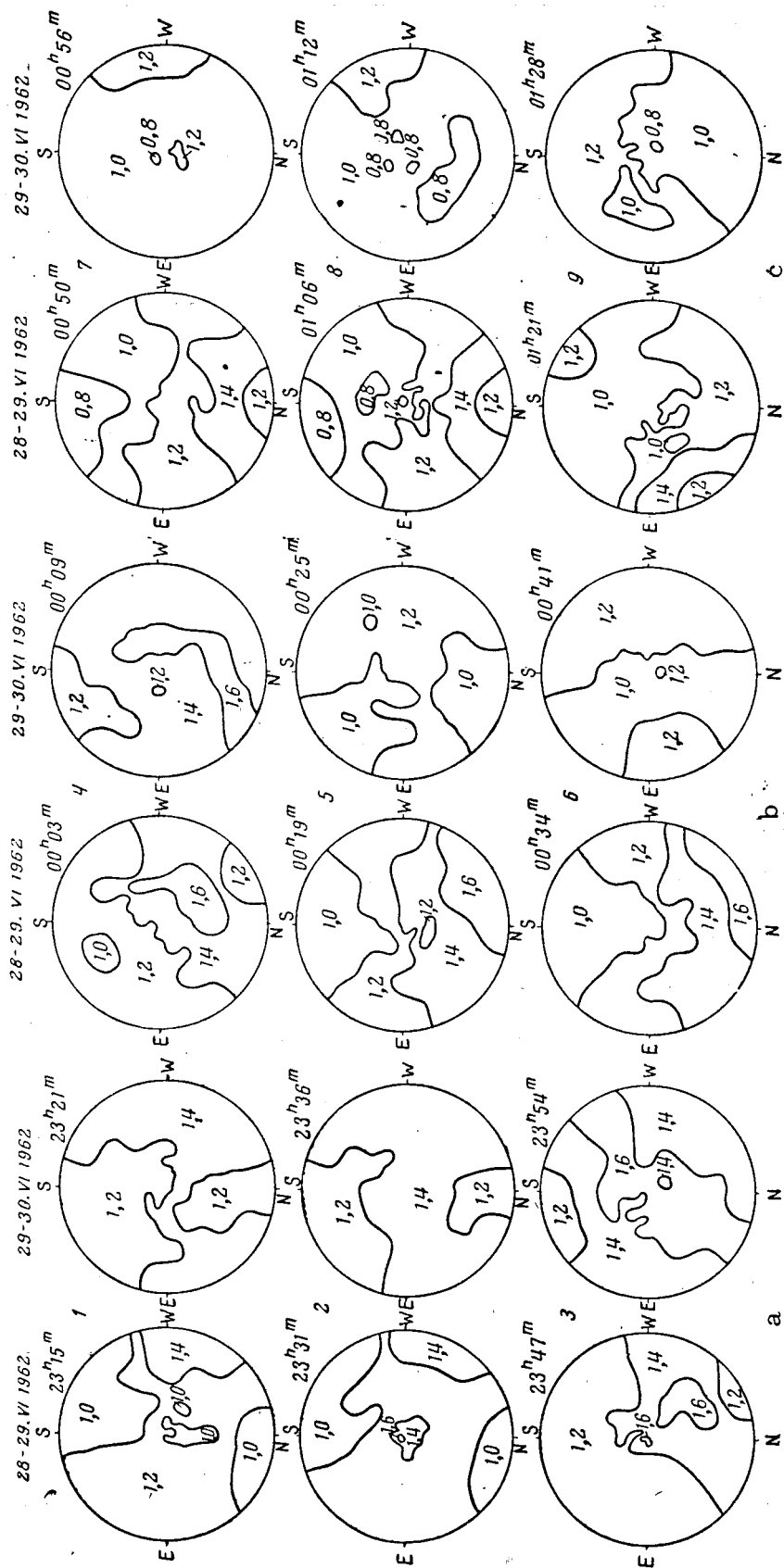


Fig. 6. Diagrams of Spatial Distribution of Intensities at 5577 Å at Similar Moments in Stellar Time for Various Nights (a,b,c) (Intensities are Given in a General System of Relative Units). The Linear Scale of the Diagrams is Uniform. The Diameter of the Scanning Region of Each Photometer is 600 km.

However, their existence is a real fact. The shape of the spots can be highly diverse, from diffuse structures of irregular shape to highly contrasting areas. Figure 7 shows such a band, observed on the night of 28-29 June 1962 at 0230 standard time. It crossed the entire scanning field of the photometer. The intensity in this band was one and a half times greater than the intensity of the radiation in adjacent regions. In addition, its western portion began to shift rather rapidly toward the north, so that the band then broke up into rather elongated spots with nonsynchronized further development. Unfortunately, the diagrams in Figure 7 do not show the development of the spots as clearly owing to the short time (16 min) and angular resolution (30°). In Figure 8, the angular resolution is 10° .

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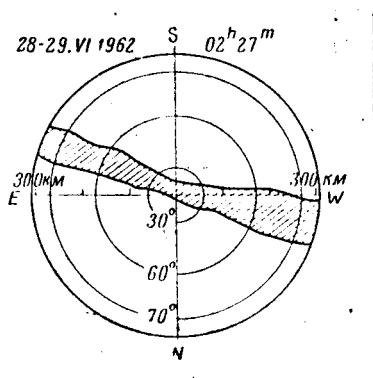


Fig. 7. Contrast Arc in 5577 Å Emission, Observed on 28-29 June 1962. A Similar Formation on the 6300 Å Emission Wavelength was not Observed. The Geomagnetic Parallel at the Point of Observation Nearly Coincides With the East-West Line.

Occasionally rather immobile spots are encountered. In Figures 8a and b, recordings of such spots have been reproduced. One of them (a) did not change its position for a period of about four hours, while the other (b) remained mobile for about one hour.

The time of existence of spots can vary from several minutes to several hours. The preferred direction of the occurrence of spots was not detected, although cases have been observed when during the course of several nights in succession the frequency of occurrence of spots was greater in one of the azimuths

than in the other directions. The increase in intensity in the spot above the intensity of the radiation in adjacent portions of the sky can reach two or three times. The intensity gradient sometimes reaches 3-4 Rayleighs/km. The time gradient can reach 40 Rayleighs/min. The occurrence of spots or increase in their number does not necessarily lead to an increase of the radiation intensity for the sky in the 5577 Å region.

The rate of motion of the spots (for obtaining an idea about the wind speed) was not measured, since observations were made at only one point. In addition, we consider it probable that the change in the distribution of the intensities in the sky can be explained not only by the drift of more or less stable regions with increased intensity, but also by changes in the intensity of the radiation at various points of the sky, caused by variation of physical parameters.

T. Tomatsu [28] feels that the error introduced by the actual motion of the isophots, can reach 33% of the speed values obtained. This number is somewhat depressed, since the value he took for the intensity of the green line $J_{5577} = 250$ Rayleighs is considerably less than the intensity given by other authors [26, 27]. Hence, the rates given in [24, 28, 32] may differ considerably from the actual values.

During the entire observation period, no recordings whatsoever were made of a single case when the occurrence of a spot coincided with an increase in the intensity in both filters. The only exceptions were found on the nights of 12-13 October 1961, when a very strong and prolonged increase in the intensity of radiation at $5577 \text{ \AA}$ at azimuth $A = 50^\circ$ [29, 30] was observed, and the same was true on the following night, 13-14 October. On these nights, a small (no more than 5%) increase in the intensity was observed in the regions $3914 \text{ \AA}$ and $5300 \text{ \AA}$.

It should be mentioned in conclusion that the existence of spots which retain their position for a rather long time, as well as certain peculiar relationships between the green and the red oxygen emissions, do not permit explanation of the spatial variations of radiation at $5577 \text{ \AA}$ solely in terms of upper atmospheric dynamics.

SPATIAL VARIATIONS OF INTENSITIES OF RED OXYGEN LINES

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As we have already mentioned above, the difficulties in distinguishing the red oxygen lines at $6300 \text{ \AA}$ and $6364 \text{ \AA}$ from the background of the integral continuum and the OH bands (5.0) and (9.3) with observations using interference filters, is considerably complicated in the investigation of their spatial inhomogeneities. The separation of the $6300 \text{ \AA}$ and $6364 \text{ \AA}$ lines in order to simplify the problem was not done.

It should be mentioned first of all that at the point of observation the radiation of the night sky at $6300 \text{ \AA}$ (unlike the radiation at $5577 \text{ \AA}$) does not have a spotty structure. It is practically uniform over the entire sky. Spatial inhomogeneities are rarely encountered. They are extremely diffuse and have a low brightness gradient. The intensity in such a inhomogeneity increases very insignificantly. To follow the change in shape of such inhomogeneities, as well as their motion, was not possible owing to their very low contrast. However, the average intensity of the radiation over the sky in this region apparently does not remain constant during the whole night. The arc M mentioned by many authors [31-38] was not observed successfully at all during the entire period of observations. This was in good agreement with the results found in [39]. Apparently we can conclude that at the point of observation at the latitude 38° N , the arc M is not found.

No increase was found in the intensity measured with the

6300 Å filter with occurrence of green spots, at position angles coinciding with the position angles of the spots. The exception to this were the nights of 12-13 and 13-14 October 1961 when a small (5-10%) increase in intensity was noted. This increase was caused

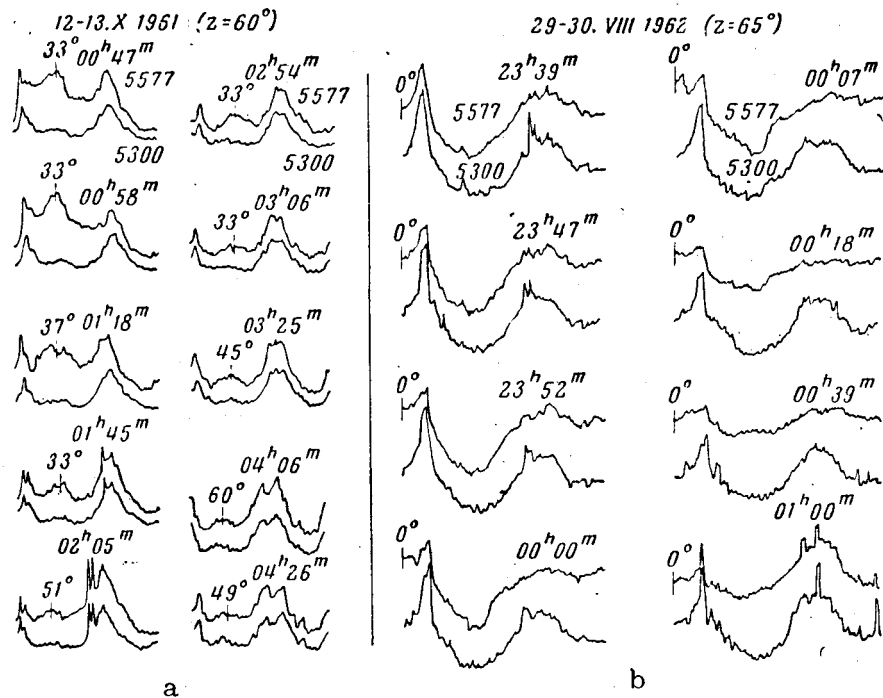


Fig. 8. Examples of Recordings of Intensities With 5577 and 5300 Å Filters for spots Which Retain Their Positions in Horizontal Coordinates for a Prolonged Period of Time. The Location of Spots on the Recordings is Shown by Vertical Lines Indicating the Azimuth of Maximum Intensity. a is the Lifetime of a Spot, Equal to 4 hrs; b is the Lifetime of a Spot, Equal to 1 hr.

by a rise in the atmospheric component of the integral continuum, and not by an increase in the red doublet. It was noticeable, however, that in several cases the occurrence of green spots was accompanied by the occurrence of inhomogeneities at 6300 Å, but with other position angles. The table lists such pairs of inhomogeneities, along with the moment of appearance, and also gives their position angles. If we look at the regularities of the occurrence of such pairs of red-green inhomogeneities, we can make the assumption that they could be caused by a flux of retarded particles and must occur along one or another magnetic line of force. As far

the details of the M arc are concerned, a similar suggestion has been made in [39]. In the case where the red and green inhomogeneities occur on one and the same magnetic line of force, their azimuths and altitudes must be linked by the relationships

$$\operatorname{tg} h_2 = \frac{H_2}{\sqrt{\frac{H_1^2}{\operatorname{tg}^2 h_1} + \frac{(H_2 - H_1)^2}{\operatorname{tg}^2 I} + 2 \frac{H_1(H_2 - H_1)}{\operatorname{tg} h_1 \operatorname{tg} I} \cos A_1}}, \quad (9)$$

$$A_2 = A_1 + \Delta A, \quad (10)$$

where

$$\sin \Delta A = \frac{(H_2 - H_1) \sin A_1}{\operatorname{tg} I \sqrt{\frac{H_1^2}{\operatorname{tg}^2 h_1} + \frac{(H_2 - H_1)^2}{\operatorname{tg}^2 I} + 2 \frac{H_1(H_2 - H_1)}{\operatorname{tg} h_1 \operatorname{tg} I} \cos A_1}} \quad (11)$$

or

$$\sin \Delta A = \frac{(H_2 - H_1) \sin A_1 \operatorname{tg} h_2}{H_2 \operatorname{tg} I}, \quad (12)$$

where H_1, H_2 are the heights of the radiation on the green line and the red doublet, respectively; h_1, h_2 are the heights of the green and red spots; A_1, A_2 are the azimuths of the green and red spots in the horizontal system of coordinates, and I is the angle of declination of the magnetic line of force as the observers location.

Inasmuch as expressions (9) and (10) are rather cumbersome, we have presented in Figure 9, graphs which make it easy to determine

COMPARISON OF OBSERVED AND CALCULATED (ON THE BASIS OF THE POSITION OF THE "GREEN" SPOTS) COORDINATES OF THE "RED" INHOMOGENEITIES

Date	Time	Coord. of center of green spots		Coord. of center of red spots			
		A_1^0	z_1^0	observed		calculated	
				A_2^0	z_2^0	A^*	z^*
28—29.VI 1962	^h ^m 01 24	120	70	68	30	66	34
	01 40	117	60	42	30	31	30
1—2.VII 1962	23 57	120	70	78	30	66	34
2—3.VII 1962	00 56	80	70	50	40	42	45
	01 52	70	70	28	50	37	47
	02 35	135	40	20	30	27	27
	02 37	116	60	47	20	43	30
	03 26	145	60	41	20	41	20
29—30.VII 1962	00 05	106	70	57	40	56	39
30—31.VII 1962	23 34	210	70	287	30	274	20
	01 44	268	70	310	40	310	37

the azimuth A_2 and the zenith distance z_2 of a red spot, corresponding to a green spot with the coordinates A_1, z_1 . It is easy to see that the coordinates of the spots as given in the table satisfy Equations (9) and (10), i.e., that each pair of these spots within the limits of observational accuracy is located on a single line of force. From this we can conclude with a sufficient degree of accuracy that these spots are produced by a flux of particles which are moving along the magnetic line of force. Hence, it is completely possible that in explaining the radiation of the green and red oxygen lines, it is necessary to keep in mind both the photochemical theory [40, 41] as well as the theory of corpuscular excitation [28].

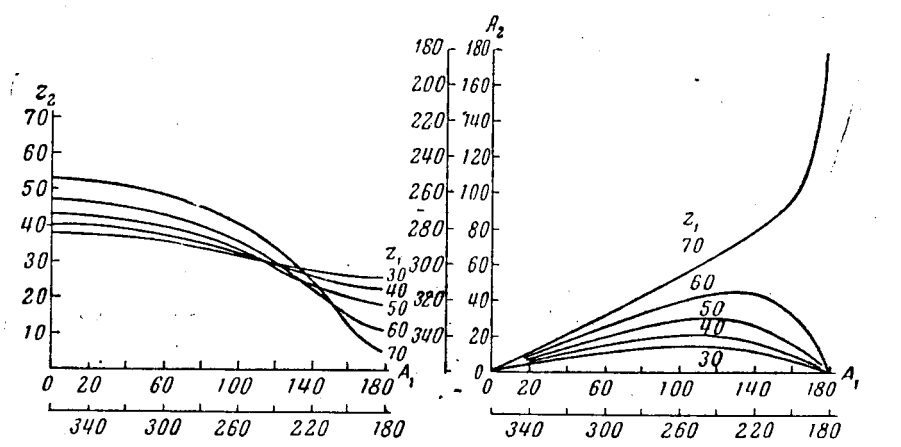


Fig. 9. Relationships Between the Horizontal Coordinates of the Green ($A_1; z_1$) and Red ($A_2; z_2$) Spots. In Calculating the Graphs, Altitudes of 100 km for the Green Spots and 400 km for the Red Spots were Used. The Angle of Declination I of the Geomagnetic Line of Force is Equal to 50° for the Observer's Location.

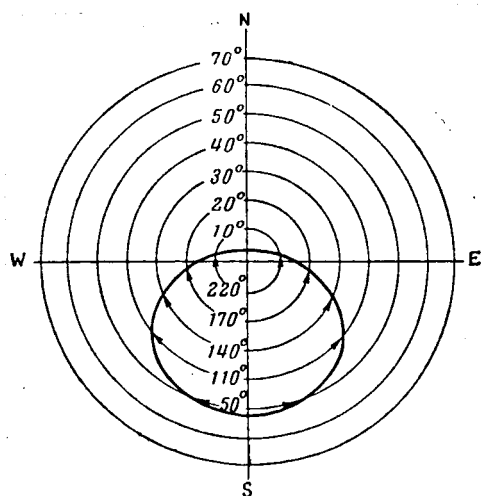


Fig. 10. Mutual Distribution of Regions of Radiation in the Sky, Located Along a Single Geomagnetic Line of Force with Declination of $I=50^\circ$ and Located at Heights of 100 and 400 km. The Field of Vision up to Zenith Distance is 70° for the Height of the Radiation of $5577 \text{ \AA}$ Emission (100 km) Corresponds to a Region of the Sky Bounded by the Oval, for the Height of the Radiation Emitted on $6300 \text{ \AA}$ (400 km).

If two mechanisms are involved in the excitation of the oxygen lines, then it is possible for there to be some correlation between the intensities of the green line and the red doublet. However this correlation must be sought not only by means of the intensities averaged over the sky, but also by means of the average intensity of the 5577 Å emission over the sky and the average intensity of the 6300 Å emission; in addition, this must be carried out for relatively small regions of the sky, whose dimensions and position depend on the declination of the magnetic lines of force at the observer's position. The position and size of the portion of the sky for a point at which the observations are carried out are given in Figure 10.

The portion of the material which was stored at the laboratory did not permit us to provide an unambiguous reply to the question of the existence of a relationship between the green line and the red doublet, owing to the difficulty of obtaining reliable values for the intensities of the red doublet in observations made with interference filters, which have an equivalent width of complete transmission on the order of 50 Å. However, it is possible that the available series of observations with narrower filters ($\Delta\lambda \approx 15$ Å) can permit answering this question. /62

Failure to take into account the geometry of the mutual positions of the details of the red and the green emission in those cases when there is a possibility of corpuscular excitation and consequent incorrect selection of scanning regions, leads to the fact that the data on the red and green emissions obtained as a result of such observations cannot be compared with one another. Thus, in [38] as an example of the absence of any increase in the intensity of 5577 emission in the presence of the *M* arc, the authors have provided charts of isophots for the night of 22 October 1958, from 1925 to 1930 Mean Standard Time, based on observations at Rapid City. The increase in the intensity of the red line was observed at azimuths $A_2 = 120-270^\circ$, and at zenith distances $z_2 = 40-80^\circ$. If we admit the possibility of a correlation between these two emissions, we must also admit a corpuscular mechanism of excitation. Consequently, the corresponding details (if they exist) of the red and green emissions must be located along the same geomagnetic line of force, and their horizontal components must be related by the Equations (9) and (10). Solving Equation (9) for h_1 , we obtain:

$$\operatorname{tg} h_1 = \frac{H_1}{\sqrt{\frac{H_2^2}{\operatorname{tg}^2 h_2} + \frac{(H_2 - H_1)^2}{\operatorname{tg}^2 I} - 2 \frac{H_2 (H_2 - H_1)}{\operatorname{tg} h_2 \cdot \operatorname{tg} I} \cos A_2}}, \quad (13)$$

where all of the symbols are the same as those in Equations (9-12).

It is easy to see that from the observed values for the azimuths of the red arcs $A_2 = 120-270^\circ$, the maximum value h_1 is ob-

tained for a value $A_2 = 270^\circ$ and amounts to 2° for $z_2 = 80^\circ$; 4° for $z_2 = 75^\circ$; 5° for $z_2 = 70^\circ$; 8° for $z_2 = 60^\circ$, and 16° for $z_2 = 40^\circ$, i.e., all the regions in which it was possible to expect increased intensity of green emission, are located outside the scanning field of the photometer. The only exception is the region which corresponds to the region of red emission with coordinates $z_2 = 40^\circ$, $A_2 = 270^\circ$, and having the corresponding coordinates $z_1 = 74^\circ$ and $A_1 = 111^\circ$. We calculate A_1 according to the formula

$$A_1 = A_2 + \Delta A, \quad (14)$$

where

$$\sin \Delta A = \frac{(H_2 - H_1) \sin A_2 \operatorname{tg} h_1}{H_1 \operatorname{tg} I}. \quad (15)$$

The value of I for Rapid City was taken equal to 67° . At this location, some increase in the emission intensity of 5577 was observed.

Hence, failure to take into account the geometry of the locations of the details of these emissions and an improper selection of scanning regions led to the fact that the material given in [38] cannot be used to obtain information as to whether or not the occurrence of an M arc is accompanied by an increase in the intensity of 5577 emission.

REFERENCES

1. Dzhordzhio, N. V.: Avtomaticheskii skaniruyushchiy fotometr (Automatic Scanning Photometer). Geomagnetizm i aeronomiya, vol. 1, No. 6, pp. 1005-1005, 1961.
2. Truttse, Yu. L.: Variatsii spektral'nogo raspredeleniya kontinuum svecheniya nochnogo neba (Variations of the Spectral Continuum of the Night-Sky Airglow). Present collection, p.1.
3. Shefov, N. N.: Intensivnosti nekotorykh emissiy nochnogo neba (Intensities of Some Emissions in the Night Sky), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric and Radar Investigations of Auroras and Night Sky Airglow), No. 2/3 in the series "Rezultaty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 57-59, 1960.
4. Struve, O., C. T. Elvey and F. E. Roach: Reflection Nebulae. Astrophys. J., Vol. 84, No. 2, pp. 219-228, 1936.
5. Karyagina, Z. V. and L. N. Tulenkova: Spektrofotometricheskoye issledovaniye nepreryvnogo spektra nochnogo neba v vizual'noy oblasti spektra (Spectrophotometric Investigation of the Continuous Spectrum of the Night Sky in the Visible Portion of the Spectrum). Izvest. Astrofiz. Inst. Akad. Nauk Kaz. SSR, Vol. 9, pp. 86-95, 1959.
6. Mironov, A. V.: Nekotoryye rezul'taty obrabotki elektrofo-

- tometricheskikh nablyudeniye izlucheniya nochnogo neba (Some Results of the Analysis of Electrophotometric Observations of Night-Sky Airglow), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric and Radar Investigations of Auroras and Night-Sky Airglow), No. 6 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 12-16, 1961.
7. Fishkova, L. M. and G. V. Markova: Nekotoryye rezul'taty elektrofotometricheskikh i spektrograficheskikh nablyudeniye svecheniya nochnogo neba v Abastumani (Some Results of Electrophotometric and Spectrographic Observations of Night-Sky Airglow at Abastumani), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric and Radar Investigations of Auroras and Night-Sky Airglow), No. 2/3 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 49-56, 1960.
 8. Shefov, N. N.: Intensivnosti nekotorykh emissiy sumerechnogo i nochnogo neba (Intensities of Several Emissions in the Twilight and Night Sky), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric and Radar Investigations of Auroras and Night-Sky Airglow), No. 1 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 25-29, 1959.
 9. Shefov, N. N.: Nepreryvnyy spektr v svechenii nochnogo neba (Continuous Spectrum in Night-Sky Airglow), in: Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric and Radar Investigations of Auroras and Night-Sky Airglow), No. 5 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 39-41, 1961.
 10. Krasovskiy, V. I.: Pis'mo v redaktsiyu (Letter to the Editor). Izvest. Akad. Nauk SSSR, Ser. Geofiz., No. 12, pp. 1898-1900, 1961.
 11. Truttse, Yu. L.: Spektral'noye raspredeleniye vneatmosfernoy i atmosfernoy kontinuum v svechenii nochnogo neba (Spectral Distribution of Extra-Atmospheric and Atmospheric Continuum in Night-Sky Airglow), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Auroras and Night-Sky Airglow), No. 10 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 5-7, 1963.
 12. Gindilis, L. M.: Absolyutnyye izmereniya nepreryvnogo spektra svecheniya nochnogo neba (Absolute Measurements of the Continuous Spectrum of the Night-Sky Airglow). Present collection, p. 27.

13. Taranova, O. G.: O staticheskoy obrabotke fotoelektricheskikh izmereniy s fil'trami (Statistical Analysis of Photoelectric Measurements with Filters). Present collection, p. 38.
14. Migulin, A. V.: O razdelenii sostavlyayushchikh kontinuumu nochnogo neba (Distribution of the Components of the Night-Sky Continuum). Present collection, p.20.
15. Truttse, Yu. L.: Izmereniya fona pri fotoelektricheskikh nabliudeniyaakh emissii [OI] $\lambda 5577 \text{ \AA}$ (Measurements of the Background in Photoelectric Observations of the [OI] Emission at $\lambda 5577 \text{ \AA}$)., in: Polyarnyye siyaniya i svecheniye nochnogo neba (Auroras and Night-Sky Airglow), No. 10 in series "Rezultaty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 8-12, 1963.
16. Barbier, D.: Photométrie photoélectrique de la luminescence du ciel nocturne aux observatoires de Haute Provence et la Tamanrasset (Mai 1957-Janvier 1960) (Photoelectric Photometry of the Night-Sky Airglow at the Observatories of Haute Provence and Tamanrasset From May 1957 to January 1960). Contrib. de l'Institut d'Astrophys. de Paris, Ser. B., No. 216, pp. 35-66, 1961.
17. Roach, F. E.: A Review of Observational Results in Airglow Photometry. Ann. Géophys., Vol. 11, No. 2, pp. 214-231, 1955.
18. Barbier, D. and J. Glaume: Contribution à l'étude de la couche qui émet la raie 5577 du ciel nocturne (Contribution to the Study of the Layer Emitting the 5577 Line in the Night Sky). Ann. Géophys., Vol. 15, No. 2, pp. 266-271, 1959.
19. Huruwata, M.: Photoelectric Studies of the Night Sky Light. Ann. Tokyo Astron. Observ., Vol. 3, No. 4, pp. 165-174, 1953.
20. Huruwata, M., H. Tanabe and T. Nakamura: Photoelectric Studies of the Night Sky Light. Rept Ionosphere Res. Japan, Vol. 9, No. 3, pp. 136-147, 1955.
21. Manring, E. R. and H. B. Pettit: Observation of the [OI]-5577 Nightglow at Sacramento Peak, New Mexico, February through June 1955. "The Airglow and the Aurorae", eds. E. B. Armstrong, A. Dalgarno. Pergamon Press, London, Suppl. J. Atmos. Terr. Phys., Vol. 5, pp. 29-37, 1956.
22. Roach, F. E., D. R. Williams and H. B. Pettit: Diurnal Variation of [OI] 5577 in the Nightglow. Astrophys. J., No. 3, pp. 456-460, 1953.
23. Roach, F. E. and H. B. Pettit: Excitation Patterns in the Nightglow. Mém. Soc. Roy. Sci. Liège, Vol. 12, Pts. 1-2, pp. 13-42, 1952.
24. Roach, F. E., E. Tandberg-Hanssen and L. R. Megill: The Characteristic Size of Airglow Cells. J. Atmos. Terr. Phys., Vol. 13, Nos. 1/2, pp. 113-121, 1958.
25. Tohmatsu, T. and T. Nagata: Dynamic Studies of the Oxygen Green Line in the Airglow. Planet. Space Sci., Vol. 10,

- pp. 103-116, 1963.
26. Atlas spektra izlucheniya nochnogo neba $\lambda\lambda$ 3000-12,400 Å (Atlas of Night-Sky Airglow on 3000-12400 Å). Institut Fiziki Atmosfery (Institute of Atmospheric Physics, Akad. Nauk SSSR, 1962.
 27. Krasovskiy, V. I., N. N. Shefov and V. I. Yarin: Atlas of the Airglow Spectrum 3000-12 400 Å. Planet. Space Sci., Vol. 9, No. 12, pp. 883-915, 1962.
 28. Tandberg-Hanssen, E. and F. E. Roach: Excitation Mechanisms of the Oxygen 5577 Emission in the Upper Atmosphere. J. Res. Nat. Bur. Standards, Vol. D63, No. 2, pp. 319-324, 1959.
 29. Truttse, Yu, L.: Anomal'noye povysheniye intensivnosti svecheniya atmosfery na uchastke λ 5577 Å (Anomalous Rise in the Intensity of the Atmosphere's Natural Glow in the λ 5577 Å Region), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Auroras and Night-Sky Airglow), No. 10 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 13-14, 1963.
 30. Truttse, Yu. L.: Anomalous Rise in the Intensity of the Atmosphere's Natural Glow in the λ 5577 Å Region. Planet. Sci., Vol. 9, No. 12, p. 993, 1962.
 31. Barbier, D.: L'activité aurorale aux basses latitudes (Auroral Activity at Low Latitudes). Ann. Géophys., Vol. 14, No. 3, pp. 334-355, 1955.
 32. Barbier, D.: L'arc auroral stable (The Stable Auroral Arc). Ann. Géophys., Vol. 16, No. 4, pp. 544-549, 1960.
 33. Barbier, D.: Les variations d'intensité de la raie 6300 Å de la luminescence nocturne (Variations in the Intensity of the 6300 Å Line of the Night-Sky Airglow). Ann. Géophys., vol. 17, No. 1, pp. 3-15, 1961.
 34. Rees, M. H. and S. I. Akasofu: On the Association Between Subvisual Red Arcs and the $D_{st}(H)$ Decrease. Planet. Space. Sci., Vol. 11, No. 1, pp. 105-107, 1963.
 35. Roach, F. E., J. G. Moore, E. C. Bruner, H. Cronin, and S. M. Silverman: The Height of Maximum Luminosity in an Auroral Arc. J. Geophys. Res., Vol. 65, No. 11, pp. 3575-3580, 1960.
 36. Moore, J. G. and F. K. Odencrantz: The Height and Geographical Position of the Red Auroral Arc of April 1-2, 1960. J. Geophys. Res., Vol. 66, No. 7, pp. 2101-2104, 1961.
 37. Tohmatsu, T. and F. E. Roach: The Morphology of Mid-Latitude 6300 Angstrom Arcs. J. Geophys. Res., Vol. 67, No. 5, pp. 1817-1821, 1962.
 38. Marovich, E. and F. E. Roach: Distribution of Latitude of Red Arcs. J. Geophys. Res., Vol. 68, No. 7, pp. 1885-1888, 1963.
 39. Roach, F. E. and J. R. Roach: Stable 6300 Å Auroral Arcs in Mid-Latitudes. Planet. Space Sci., Vol. 11, No. 5, pp. 523-545, 1963.
 40. Bates, D. R.: Physics of the Upper Atmosphere (Ed. J. A.

- Ratcliffe), Academic Press, New York, Chapter V, pp. 219-267, 1960.
41. Chamberlain, J. W.: Physics of the Aurora and Airglow, Academic Press, New York, 1961.

RADIATION OF INERT GASES IN THE ATMOSPHERE

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ABSTRACT: An evaluation of the intensity of the argon and neon lines in the twilight glow and in the sunlit auroras is made. The expected intensity of argon lines in the twilight is of the order of 0.1 Rayleigh and in the auroras it is of the order of 10 Rayleighs.

Radiation of the lightest inert gas (helium, $\lambda 10830 \text{ \AA}$) can be observed only when the upper layers of the atmosphere are illuminated by the Sun. This is caused by the fluorescence of metastable atoms of helium in the solar radiation. /65

However, the Earth's atmosphere contains other inert gases besides helium: neon, argon, krypton, xenon. Their content in the atmosphere is very low. The most abundant is argon, $\sim 10^{-2}$ by volume. Neon, $\sim 2 \cdot 10^{-5}$, krypton 10^{-6} , and xenon 10^{-7} [1]. Studies with the aid of rockets show a concentration of argon atoms at heights of about 200 km to be about 10^8 cm^{-3} [2, 3].

Like helium, argon and neon have singlet and triplet states, of which the lower Ne ($3s^3P^o$) and Ar ($4s^3P^o$) are metastable.

However, the lifetimes of atoms in these metastable states in the absence of deactivating collisions is less than for helium. Unlike the helium atom, argon and neon atoms have the possibility for intercombination transitions.

The theory of helium radiation in the upper atmosphere has already been discussed [4-7]. Due to the fluorescence of metastable atoms in the solar radiation, it is also possible to have excitation of the argon and neon lines. However, unlike helium, argon and neon must have not merely one intense emission but several lines in the visible and near infrared regions of the spectrum. The probabilities of transitions for neon lines in this region of the spectrum were discussed in [8], and the resonance ultraviolet lines were discussed in [9].

The probabilities of transitions of several neon lines with

general upper levels were obtained on the basis of data in [10]. The power of the oscillator for the resonance line of argon was given in [11, 12]. These data are listed in Tables 1 and 2.

The calculation of the intensity of the emissions of argon and neon is completely analogous to the calculation for helium [4-7]. Intensity of the line corresponding to the transition between the k and m levels, is determined by the following formula:

$$J_{km} = \rho_{km} W B_{mk} \frac{A_{km}}{A_{km} + \sum_i A_{ki}} H \sigma \frac{n_0 F}{A_{m0} + C + \sum \sigma_m M v},$$

where ρ_{km} is the radiation density of the Sun on the km line; W is the dilution factor, A_{km} is the probability of spontaneous transition from the k level to the metastable level m ; A_{ki} from the k level to the i level; A_{m0} from the metastable level m to the ground level; B_{mk} for the transition $m-k$ with absorption of light; H is the altitude of a uniform atmosphere for argon or neon; n_0 is the concentration of atoms of argon or neon; σ is the effective cross section for excitation of metastable levels by electron collision with energies of about 15 eV (for argon) and 20 eV (for neon); F is the electron flux of such energies; σ_m is the effective cross section for deactivation of metastable states of argon or neon during collisions with particles M (atoms and molecules of oxygen and nitrogen); C is the number of photoionization processes of metastable atoms. /66

Inasmuch as it is possible for atoms of argon and neon to have intercombination transitions, a result of the fluorescence of metastable atoms in solar radiation may be not only triplet lines but also lines which correspond to singlet transitions. Tables 1 and 2 show the other intensities of the lines of the solar spectrum, corresponding to the wavelengths of argon and neon, for which the lower level is metastable. /67

According to the formula given above, it is possible to estimate the expected intensities of the argon and neon lines. Since the values of r are close to unity, for the most intense lines we will have values of $\rho W B \sim 10$. The effective cross sections of excitation by electron collision according to the data in [10, 13, 14] are 10^{-19} - 10^{-20} cm².

The cross sections σ_m of deactivation of metastable levels of argon and neon were assumed to be the same as for helium [15-18]. The number of photoionization processes C for argon and neon is close to the corresponding value for helium ($1.2 \cdot 10^{-3}$). If we assume that $H \sim 3 \cdot 10^6$ cm, $F \sim 10^9$ cm⁻² and $n_0(\text{Ar}) \sim 10^8$ cm⁻³, we will obtain $J(\text{Ar}) \sim 0.1$ Rayleighs. Inasmuch as the content of neon in the atmosphere is less than that of argon, then the intensity of the neon emission must be still less. If we analyze the spectra of the twilight radiation of the atmosphere, as recorded at Zvenigorod, we cannot detect any argon or neon lines. /68

TABLE 1. WAVELENGTHS OF NEON LINES

$\lambda, \text{\AA}$	Transition	$\lambda(10^3)$	r	Blending
5852,4880	$3p^1S_0 - 3s^1P_1^{\circ}$	12,8	—	(10,6) IPGN ₂
5400,5620	$3p^1S_0 - 3s^3P_1^{\circ}$	0,13	0,4	—
6598,9528	$3p^3P_1 - 3s^1P_1^{\circ}$	4,32	—	(6,3) IPGN ₂
6163,5937	$3p^3P_1 - 3s^3P_0^{\circ}$	2,44	0,9	(12,9) IPGN ₂
6029,9970	$3p^3P_1 - 3s^3P_1^{\circ}$	~1,2	1,0	p_6 (8,2) OH
5882,8950	$3p^3P_1 - 3s^3P_2^{\circ}$	2,12	1,0	—
6652,0925	$3p^3P_0 - 3s^1P_1^{\circ}$	(1)	—	(5,2) IPGN ₂
6074,3377	$3p^3P_0 - 3s^3P_1^{\circ}$	7,8	1,0	(5,4) IPGN ₂
6678,2766	$3p^3P_2 - 3s^1P_1^{\circ}$	4,10	—	(4,4) IPGN ₂
6096,1630	$3p^3P_2 - 3s^3P_1^{\circ}$	2,36	1,0	P_8 (8,2) OH
5944,8343	$3p^3P_2 - 3s^3P_2^{\circ}$	1,7	1,0	p_3 (8,2) OH
6717,0428	$3p^1P_1 - 3s^1P_1^{\circ}$	4,17	—	—
6266,4950	$3p^1P_1 - 3s^3P_0^{\circ}$	3,93	1,0	Q ₂ (9,3) OH
6128,4498	$3p^1P_1 - 3s^3P_1^{\circ}$	<0,6	1,0	(5,1) IPGN ₂
5975,5340	$3p^1P_1 - 3s^3P_2^{\circ}$	~0,9	1,0	(1,4) INGO ₂ ⁺
6929,4678	$3p^1D_2 - 3s^1P_1^{\circ}$	3,56	—	(9,7) IPGN ₂
6304,7893	$3p^1D_2 - 3s^3P_1^{\circ}$	0,92	1,0	P_2 (9,3) OH, OI
6143,0624	$3p^1D_2 - 3s^3P_2^{\circ}$	3,25	1,0	r_1 (5,0) OH
7024,0508	$3p^3D_1 - 3s^1P_1^{\circ}$	(2)	—	(4,1) MN ₂ ⁺
6532,882	$3p^3D_1 - 3s^3P_0^{\circ}$	2,14	0,9	P_1 (6,4) OH
6382,9914	$3p^3D_1 - 3s^3P_1^{\circ}$	4,17	1,0	—
6217,2811	$3p^3D_1 - 3s^3P_2^{\circ}$	1,5	1,0	—
7173,9389	$3p^3D_2 - 3s^1P_1^{\circ}$	0,80	—	—
6506,5278	$3p^3D_2 - 3s^3P_1^{\circ}$	3,4	1,0	Q ₃ (6,1) OH
6334,4280	$3p^3D_2 - 3s^3P_2^{\circ}$	2,07	1,0	—
6402,2455	$3p^3D_3 - 3s^3P_2^{\circ}$	5,78	1,0	—
8082,4580	$3p^3S_1 - 3s^1P_1^{\circ}$	(0,4)	—	(3,4) MN ₂ ⁺
7438,8990	$3p^3S_1 - 3s^3P_0^{\circ}$	(1)	1,0	P_5 (8,3) OH
7245,1668	$3p^3S_1 - 3s^3P_1^{\circ}$	1,8	1,0	R (8,3) OH
7032,4134	$3p^3S_1 - 3s^3P_2^{\circ}$	3,24	0,8	—
735,89	$3s^1P_1^{\circ} - 1S_0$	80		
743,70	$3s^3P_2^{\circ} - 1S_0$			

However this does not mean that it is completely impossible to observe argon lines.

During the occurrence of auroras, illuminated by the Sun, it is obviously possible to have the occurrence of argon lines with an intensity on the order of tens of Rayleighs.

In addition to the mechanism of fluorescence, the excitation of argon and neon lines may also see the contribution of the direct excitation of the emissions of these atoms by electron impact.

TABLE 2. WAVELENGTHS OF ARGON LINES

$\lambda, \text{\AA}$	Transition	A(10 ⁷)	r	Blending
7503,8676	$4p^1S_0-4s^1P_1^{\circ}$		—	R (4,0) OH, (4,2) IPGN ₂
6677,28	$4p^1S_0-4s^3P_1^{\circ}$		1,0	(4,1) IPGN ₂
8264,5209	$4p^3P_1-4s^1P_1^{\circ}$		—	—
7724,2064	$4p^3P_1-4s^3P_0^{\circ}$		1,0	(2,0) IPGN ₂
7272,9357	$4p^3P_1-4s^3P_1^{\circ}$		0,6	Q ₁ (8,3) OH
6965,4302	$4p^3P_1-4s^3P_2^{\circ}$		0,9	p ₄ (7,2) OH
8408,2094	$4p^3P_2-4s^1P_1^{\circ}$		—	—
7383,9800	$4p^3P_2-4s^3P_1^{\circ}$		1,0	(5,3) IPGN ₂
7067,2170	$4p^3P_2-4s^3P_2^{\circ}$		1,0	(4,1) M N ₂ ⁺
8521,4407	$4p^1P_1-4s^1P_1^{\circ}$		—	—
7948,1754	$4p^1P_1-4s^3P_0^{\circ}$		1,0	p ₁ (5,4) OH
7465,6468	$4p^1P_1-4s^3P_1^{\circ}$		1,0	—
7147,0408	$4p^1P_1-4s^3P_2^{\circ}$		1,0	P ₆ (7,2) OH
8580,2386	$4p^3P_0-4s^1P_1^{\circ}$		—	—
7514,6510	$4p^3P_0-4s^3P_1^{\circ}$		1,0	R (4,0) OH
9224,498	$4p^1D_2-4s^1P_1^{\circ}$		—	P ₈ (7,3) OH
8006,1556	$4p^1D_2-4s^3P_1^{\circ}$		1,0	—
7635,1053	$4p^1D_2-4s^3P_2^{\circ}$		0,0	(0,0) O ₂
9354,218	$4p^3D_1-4s^1P_1^{\circ}$		—	—
8667,9430	$4p^3D_1-4s^3P_0^{\circ}$		0,9	(0,1) O ₂
8103,6922	$4p^3D_1-4s^3P_1^{\circ}$		1,0	P ₅ (5,4) OH
7723,7597	$4p^3D_1-4s^3P_2^{\circ}$		1,0	(2,0) IPGN ₂
9784,5010	$4p^3D_2-4s^1P_1^{\circ}$		—	—
8424,6473	$4p^3D_2-4s^3P_1^{\circ}$		1,0	—
8014,7856	$4p^3D_2-4s^3P_2^{\circ}$		1,0	p ₃ (5,1) OH
8115,3115	$4p^3D_3-4s^3P_2^{\circ}$		1,0	—
11438,108	$4p^3S_1-4s^1P_1^{\circ}$		—	—
10470,051	$4p^3S_1-4s^3P_0^{\circ}$		1,0	P ₃ (4,1) OH
9357,7841	$4p^3S_1-4s^3P_1^{\circ}$		1,0	H ₂ O
9122,9660	$4p^3S_1-4s^3P_2^{\circ}$		0,9	H ₂ O
1048,22	$4s^1P_1^{\circ}-1S_0$	(50)		
1066,66	$4s^3P_2^{\circ}-1S_0$			

Blending of the argon and neon line emissions of the night sky and auroras is shown in the tables.

REFERENCES

1. Mitra, S. K.: Verkhnyaya atmosfera (The Upper Atmosphere). Foreign Language Publishing House, 1952.
2. Pokhunkov, A. A.: Issledovaniye neytral'nogo sostava verkhney atmosfery na vysotakh vyshe 100 km (Study of the Neutral Component of the Upper Atmosphere at

- Heights above 100 km). Izvest. Akad. Nauk SSSR, Ser. Geofiz., No. 1, p. 1649-1657, 1960.
3. Pokhunkov, A. A.: Mass-spektrometricheskiye issledovaniya strukturnykh parametrov zemnoy atmosfery na vysotakh ot 100 do 210 km (Mass Spectrometer Investigations of the Structural Parameters of the Earth's Atmosphere at Heights from 100 to 210 km), in: Iskusstvennyye sputniki Zemli (Artificial Earth Satellites), Izdatel'stvo Akad. Nauk SSSR, No. 7, p. 89-100, 1961.
 4. Shefov, N. N.: Emission de l'hélium dans la haute atmosphère (Helium Emission in the Upper Atmosphere). Ann. Geophys., Vol. 17, No. 4, p. 395-402, 1961.
 5. Shefov, N. N.: Sur l'émission de l'hélium dans la haute atmosphère (Helium Emission in the Upper Atmosphere). Ann. Geophys., Vol. 18, No. 1, p. 125, 1962.
 6. Shefov, N. N.: Emissiya geliya vo verkhney atmosfere (Helium Emission in the Upper Atmosphere), in: Pol'yarnyye siyaniya i svecheniye nochnogo neba (Auroras and Night-Sky Airglow), No. 8 in series "Rezultaty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, p. 50-65, 1962.
 7. Shefov, N. N.: Helium in the Upper Atmosphere. Planet. Space Sci., Vol. 10, pp. 73-77, 1963.
 8. Ladenburg, K. F. and K. L. Levy: Untersuchungen über die anomale Dispersion angeregter Gase. VIII Teil. Die Uebergangswahrscheinlichkeiten der rot-gelben Neonlinien (s-p) und die Lebensdauer der p-Zustände (Investigations of the Anomalous Dispersion of Excited Gases. Part VIII. Transition Probabilities of the Reddish-Yellow Neon Lines (s-p) and the Lifetimes of the p-States). Z. Physik, Vol. 88, No. 7/8, p. 461-468, 1934.
 9. Schütz, W.: Ueber die natürliche Breite der Neonlinien im sichtbaren Spectrum. I. Fragestellung, theoretische Grundlage der Untersuchungsmethoden, erste Ergebnisse und Diskussion der zur Zeit vorliegenden Ergebnisse (The Natural Width of Neon Lines in the Visible Spectrum. I. Formulation of the Problem, Theoretical Basis of the Method of Investigation, Preliminary Results, and Discussion of Available Data). Ann. Physik., Vol. 18, No. 7, p. 705-720, 1933.
 10. Kagan, Yu. M., R. I. Lyagushchenko and A. D. Khakhayev: O vozbuzhdenii inertnykh gazov v polozhitel'nom stolbe razryada pri srednikh davleniyakh. I. Neon (Excitation of Inert Gases in a Positive Charge Column at Average Pressures. I. Neon). Optika i spektroskopiya, Vol. 14, No. 5, p. 598-606, 1963.
 11. Herzfeld, K. F. and K. L. Wolf: Prüfung der klassischen Dispersionsformel an einatomigen Gasen und Dämpfen (Test of the Classical Dispersion Formula on Monatomic Gases and Vapors). Ann. Physik, Vol. 76, No. 1, pp. 71-105, 1925.

12. Herzfeld, K. F. and K. L. Wolf: Berichtigung zu der Arbeit, "Prüfung der klassischen Dispersionsformel an einatomigen Gasen und Dämpfen." (Correction to the Paper, "Test of the Classical Dispersion Formula on Monoatomic Gases and Vapors). Ann. Physik, Vol 76, No. 6, pp. 567-568, 1925.
13. Guk, S. S. and A. M. Devyatov: Opredeleeniye funktsiy vzbuzhdeniya. II. Funktsii vzbuzhdeniya nekotorykh spektral'nykh liniy neona v absolyutnykh yedinit'sakh (Determination of the Excitation Functions. II. Excitation Functions of Several of the Spectral Lines of Neon in Absolute Units). Vestnik Moskov. Univ., No. 2, pp. 103-110, 1957.
14. Volkova, L. M.: Effektivnyye secheniya vzbuzhdeniya nekotorykh liniy kaliya i argona (Effective Cross Section of Excitation of Several Lines of Potassium and Argon). Izvest. Akad. Nauk SSSR, Ser. Fiz., Vol. 23, No. 8, pp. 968-970, 1959.
15. Ferguson, E. E.: Consideration on Helium Emission $\lambda 10830 \text{ \AA}$ in Aurorae. Planet. Space Sci., Vol. 9, No. 5, pp. 286-287, 1962.
16. Ferguson, E. E. and H. S. Schlüter: Metastable Helium Atom Consideration in the Earth's Atmosphere. Planet. Space Sci., Vol. 9, No. 10, pp. 701-710, 1962.
17. Benton, E. E., E. E. Ferguson, F. A. Matsen and W. W. Robertson: Cross Section for the De-excitation of Helium Metastable Atoms by Collision with Atoms. Phys. Rev., Vol. 128, No. 1, pp. 206-209, 1962.
18. Sholette, W. P. and E. E. Muschlitz: Ionizing Collisions of Metastable Helium Atoms in Gases. J. Chem. Phys., Vol. 36, No. 12, pp. 3368-3373, 1962.

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RELATIVE INTENSITIES OF EMISSIONS IN THE VISIBLE REGION OF THE SPECTRUM OF THE AURORA

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ABSTRACT: Relative intensities are obtained of atomic oxygen lines in 15 auroral spectra, which were photographed at Loparskaya and at Zvenigorod in 1957-1960. The intensities of the lines vary considerably. A "compound" auroral spectrum was obtained by combining three "atomic" spectra.

During the IGY and the IGS and subsequent years, observations of auroras were carried out with standard spectrographs at the Loparskaya, Zvenigorod, and Roshchino stations of the Institute for Atmospheric Physics of the Academy of Sciences of the USSR.

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A description of the instruments and the method of obtaining the spectra have been described in [1, 2, 3]. A significant portion of the results of the analyses of these spectra has been published previously [4, 5]. However, there is still a small amount of data to be presented relative to the intensities of the individual emissions in the visible.

In order to obtain relative intensities of the lines of atomic oxygen, a great many "atomic" spectra with good resolution were selected. Sixty-two spectra were recorded on the MF-4 microphotometer of which 15 proved to be suitable for analysis.

The darkenings corresponding to the lines chosen were converted to intensities, the areas of the curves were measured, and a correction was made for the spectral sensitivity of the film. The correction for atmospheric transparency was not made.

The relative intensities of the lines are shown in Table 1. It is clear that it is desirable to have spectra of auroras which are obtained simultaneously over a wide range of wavelengths. No such spectra were recorded at Loparskaya, since all the observations were made with a single SP-48 spectrograph. Therefore, it was necessary in the visible region of the spectrum to compare spectra which were not obtained simultaneously in overlapping re-

regions of the spectrum.

At the same time, we knew that the relative intensities of atomic and molecular emissions, as well as the relative intensities of the atomic lines, change from one spectrum to the next [6]. These results were supported by the results of existing measurements. In order to get rid of any disagreement between the spectrograms to the degree that was possible, we selected three "atomic" spectra which were recorded and analyzed at Loparskaya on the SP-48 spectrograph:

20-21 December 1957, in the "red", 5800-6600 Å;
10-11 February 1958 in the "green", 4700-6200 Å;
16-17 February 1958, in the "violet", 3900-4900 Å.

The intensities of the "violet" and "green" spectra were expressed in a general system of units thanks to the fact that at the bands of the first negative system N_2^+ (0.1) $\lambda 4278$ Å, (0.2) $\lambda 4709$ Å, (0.3) $\lambda 5228$ Å, the upper rotational level was general, so that the ratio of their intensities had to be constant. Let us assume that it is equal to the theoretical value [7]:

$$\frac{J_{4278}}{J_{4709}} = 17; \quad \frac{J_{4278}}{J_{5228}} = 30.3.$$

Using the "green" spectrum as a basis, it is possible by using these relationships to change the intensity of the "violet" spectrum so that in the "component" spectrum the ratio of the intensities of the bands mentioned was equal to the theoretical value. Note that in the spectrum for 10-11 February 1958, the ratio is not equal to the theoretical value but is greater than 4. If we consider however, that the 4709 Å line is located at the edge of the spectrum, i.e., that its vignetting is unavoidable, this ratio becomes still greater. Therefore this attachment of the "violet" spectrum to the "green" may have to be reconsidered after the required measurement of the actual value of the ratios J_{4278}/J_{5228} and J_{4709}/J_{5228} . However, thus far we have been using ratios taken from [7]. The intensity of the 5228 Å line in the "green" is used as the unit of intensity. It follows from the ratios given above that for a "component" spectrum the intensity of the 4709 Å and 4278 Å lines must be equal to 1.8 and 30.3, respectively. In the "violet" spectrum, however, they amount to 2.8 and 46, respectively. Consequently, the intensities of the spectra in the general system will be equal to unity if the intensity of the "violet" spectrum decreases by a factor of 1.5. /71

The "red" spectrum can be converted to the "green" in another way. Using the numerous observations of auroras as a basis [9], it is possible to state that the distribution of the intensities in the rotational structure of the nitrogen molecule $1PGN_2$ changes only slightly. However, since these bands are distributed in overlapping regions of the "green" and "red" spectra, it is possible

to have a combination of the simultaneous spectra. This was done as follows (the method was analogous to that used to determine the relative intensity of the 1PGN_2 bands, in different spectra [9]).

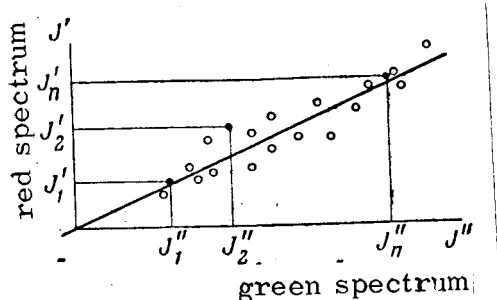


Fig. 1. Graph for Determining Coefficient of Transition From the "Green" to the "Red" Spectrum.

In this particular case, we have $k = 2.25$, i.e., the intensity of the "red" spectrum has been increased by a factor of 2.25.

The spectrum of an aurora formed in the same way is given in Figure 2. It is clear that the picture which is obtained cannot be replaced by a spectrum photographed simultaneously over the entire spectral range. For example, as we have already mentioned, the relative intensities of the atomic lines which are resolved can change from one case to the next, as we see from Table 1, so that such a method makes it possible to get only a qualitative idea regarding the distribution of the intensities in the auroral spectra. Nevertheless, such an average picture is of value.

Table 2 lists the relative intensities of some emissions of the "component" spectrum. A glance at it will show that the lines of atomic oxygen and atomic nitrogen have a considerable intensity, if their potentials of excitation do not exceed 12.5 eV, while for high excitation potentials the intensity of the lines drops sharply. At the same time, the OII and NII ions are intensely excited up to 20-27 eV (e.g., the line OII $\lambda 4415 \text{ \AA}$ and the line NII $\lambda 5004 \text{ \AA}$). We may assume that such a "gap" in the intensities is caused either by specific scattering of electrons by energies or by a low value of the excitation cross sections of the OI and NI levels close to the ionization potential.

For a great many values of $\lambda(\lambda_1, \lambda_2, \dots, \lambda_n)$ we find the intensity readings.

In the "red" we have $J'_1, J'_2, \dots, J'_n$ and in the "green" we have $J''_1, J''_2, \dots, J''_n$.

Let us plot on the graph the points with the coordinates $(J'_1, J''_1), (J'_2, J''_2), \dots, (J'_n, J''_n)$ and draw the line $y = kx$ through the group of points (Fig. 1). In this par-

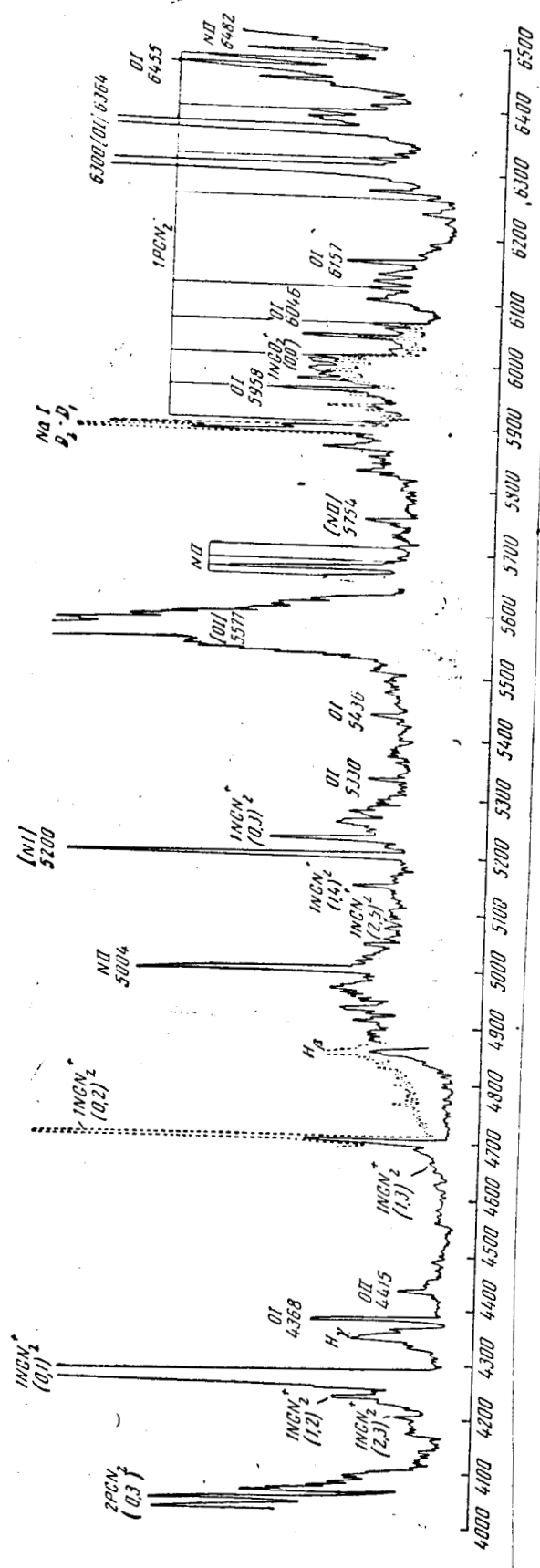


Fig. 2. "Component" Spectrum of Aurora.

TABLE 1. RELATIVE INTENSITIES OF LINES OF ATOMIC OXYGEN
IN AURORAL SPECTRA.

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Date	spec- trum no.	λ							factor
		6456	6156	5436	6046	5956	5330	4968	
10-11. II 1958	1			1,68	1,08	1,21	1,83	0,89	1/1000
	2			0,52	1,08	1,29	0,85	0,50	1/600
	3			0,9	1,08	2,08	1,20	1,20	1/250
20-21. XII 1957	1	2,5	1,2		1,16	1,1			1/150
23. II 1957	1	1,67	1,2		1,06	0,87			1/150
15. X 1957	1			0,84	2,26	3,46	1,06		1/150
5. XII 1959	1	2,27	1,07		1,05	1,55			1/400
30.XI-1.XII 1960	1			1,08	0,92	1,56	1,25		1/400
17-18.XII 1960	1	1,33	0,75		1,07	1,8			1/150
7-8.XII 1960	1			1,08	1,24	1,28	0,78		1/150
5-6.XII 1959	1			1,5	0,75	1,22	0,95		1/400
	2			0,8	1,38	1,58	0,74		1/500
	3			1,55	0,92	1,06	1,61		1/400
5.XII 1959									
Zvenigorod	1			1,60	1,0		1,40	1,2	—

TABLE 2. RELATIVE INTENSITY OF SEVERAL LINES IN THE
"COMPONENT" SPECTRUM.

atom or molecule	transition	$\lambda, \text{\AA}$	relative intensity		
			violet spectrum	green spectrum	red spectrum
N_2^+	1NG (2,3)	4199	0,28		
	1NG (1,2)	4236	0,73		
	1NG (0,1)	4278	overexposed		
OII	$3s^4P - 3p^4P^o$	4317	0,13		
H	H_γ	4340	1,23		
OI	$3s^3S^o - 4p^3P$	4368	1,60		
OII	$3s^2P - 3p^2D$	4415	0,52		
N_2^+	1NG (1,3)	4652	0,07		
	1NG (0,2)	4709		overexposed	
H	H_β	4861	1,73	2,20	
NII	$3p^2D - 3d^3F^o$	5004		1,90	
N_2^+	1NG (1,4)	5149		0,53	
NI	$2p^3^4S^o - 2p^3^2D^o$	5200		4,20	
N_2^+	1NG (0,3)	5228		1,67	
OI	$3p^5P - 5d^5D^o$	5330		0,43	
OI	$3p^5P - 6s^5S^o$	5436		0,78	
NII	$3p^3D - 3s^3P^o$	5679		2,65	
Na	$3p^2P - 3s^2S$	5890-5896		3,5	overexposed
OI	$3p^3P - 5d^3D^o$	5958		0,83	1,1
OI	$3p^3P - 6s^3S^o$	6046		0,74	1,1
OI	$3p^5P - 4d^3D^o$	6156			0,98
OI	$3p^5P - 5s^5S^o$	6456			2,64

Note. The intensity of the green line [OI] 5577 Å is taken as 100.
 J_{5577} is assumed equal to 60 J_{5228} .

REFERENCES

1. Gal'perin, Yu. I.: Vodorodnaya emissiya i dva tipa spektrov polyarnykh siyaniy (Hydrogen Emission and Two Types of Aurora), in: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric, and Radar Investigations of Auroras and Night-Sky Airglow), No. 1 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, p. 7-19, 1959.
2. Shuyskaya, F. K.: Nekotoryye rezul'taty spektroskopicheskikh issledovaniy polyarnykh siyaniy (Some Results of Spectroscopic Investigations of Auroras), in: Spektral'nyye, elektrofotometricheskiye, i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba (Spectral, Electrophotometric, and Radar Investigations of Auroras and Night-Sky Airglow), No. 1 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, p. 45-47, 1959.
3. Gerasimova, N. G. and A. V. Yakovleva: Komplekt svetosil'nykh spektrografov s diffraktsionnymi reshetkami (System of High-Intensity Spectrographs with Diffraction Gratings), in: Pribory i tekhnika eksperimenta (Apparatus and Technique of Experimentation), No. 1, p. 83-86, 1956.
4. Krasovskiy, V. I.: Nekotoryye rezul'taty issledovaniy polyarnykh siyaniy i izlucheniya nochnogo neba vo vremya MGG i MGS (Some Results of Investigations of Auroras and Night-Sky Airglow during the IGY and IGC), Uspekhi fiz. nauk., Vol. 75, No. 3, p. 501-525, 1961.
5. Chamberlain, J. W.: Physics of the Aurora and Airglow, Academic Press, New York, 1961.
6. Bates, D. R.: General Character of Auroras. Physics of the Upper Atmosphere. Ch. 6, the Aberdeen University Press, pp. 269-296, 1960.
7. Remy, L.: Identifications moléculaires (Molecular Identification). Mém. Roy. Soc. Sci. Liège, Vol. 11, No. 2/3, 1960.
8. Omholt, A.: The Red and Near-Infrared Auroral Spectrum. J. Atm. Terr. Phys., Vol. 10, No. 5/6, pp. 320-331. 1957.
9. Gal'perin, Yu. I. and O. T. Yurchenko: Poiski variatsiy kontura H α (Research on Variations of the H α Curve), in: Polyarnyye siyaniya i svecheniye nochnogo neba (Auroras and Night-Sky Airglow), No. 9 in series "Rezul'taty MGG" (Results of the IGY). Izdatel'stvo Akad. Nauk SSSR, pp. 24-31, 1962.

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